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# VETERANS' ADMINISTRATION'S RESEARCH PROGRAM ON PROSTHETICS AND REHABILITATION

## HEARING

BEFORE THE

SUBCOMMITTEE ON
HOSPITALS AND HEALTH CARE

OF THE

## COMMITTEE ON VETERANS' AFFAIRS
## HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

SECOND SESSION

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MAY 8, 1984

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**Serial No. 98-51**

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Printed for the use of the Committee on Veterans' Affairs

U.S. GOVERNMENT PRINTING OFFICE
37-378 O WASHINGTON : 1984

H761-27

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# THE VETERANS' ADMINISTRATION'S RESEARCH PROGRAM ON PROSTHETICS AND REHABILITATION

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TUESDAY, MAY 8, 1984

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON HOSPITALS AND HEALTH CARE,
COMMITTEE ON VETERANS' AFFAIRS,
*Washington, DC.*

The subcommittee met, pursuant to notice, at 9:07 a.m., in room 334, Cannon House Office Building, Hon. Bob Edgar (chairman of the subcommittee) presiding.

Present: Representatives Edgar, Penny, Slattery, Florio, Daschle, Hammerschmidt, McEwen, and Bilirakis.

Also present: Representative Montgomery (ex officio).

## OPENING STATEMENT OF CHAIRMAN EDGAR

Mr. EDGAR. Good morning. The subcommittee will come to order.

This is the second in a series of three hearings dealing with the VA's medical research program. On April 26, we heard testimony on the VA's research efforts on neurological disorders and were privileged to receive testimony from Dr. Albert Sabin, the developer of the oral polio vaccine. Today we will hear testimony on the VA's medical research program on prosthetics and rehabilitation.

I don't believe that many are aware of the tremendous contributions VA medical researchers have made in the field of prosthetics and rehabilitation. Toward the end of World War II, battle casualties began returning to the United States at the rate of 1,200 per day. The public was appalled at the plight of those who had lost limbs in the service of their country. The situation was chaotic, since the U.S. companies manufacturing prosthetics had no standards on uniformity or quality. Each manufacturer had his own designs and little organized research had been done in the previous 50 years to improve the design of artificial limbs. Additionally, prevailing Government policy required the VA to purchase prostheses from the lowest bidder and not from the manufacturer producing the highest quality devices. GI's were forced to wait months for artificial limbs.

In November 1945, Gen. Omar N. Bradley became the VA Administrator. One of his first acts was to establish the Prosthetic Appliance Service. The need to find new and improved prostheses for GI amputees launched the medical research program which established the VA as a world leader in medical and prosthetic research. Heavy leather and wood devices were used until approximately 5

years after World War II. Then steel and plastics began to be used which were lighter and easier for an amputee to wear.

We have come a long way from those crude devices, as evidenced by the high-tech items you see around the room this morning. We have a robotic arm that responds to verbal commands, an omni-directional wheelchair, and the Seattle Foot, which is molded of fiber glass and foam. Following this hearing, several devices will be on exhibit at the Rayburn horseshoe until 3 p.m. Also following this hearing we will have an opportunity to see many of these devices demonstrated. As chairman of this subcommittee, I am going to take it upon myself to do a little jogging in the rain with one of the individuals here who is a double amputee using some of these new devices. I look forward to that demonstration.

I would like now to call on the ranking minority member of the subcommittee, Hon. John Paul Hammerschmidt from Arkansas, for any remarks he may wish to make.

## STATEMENT OF HON. JOHN PAUL HAMMERSCHMIDT, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ARKANSAS

Mr. HAMMERSCHMIDT. Thank you, Mr. Chairman.

Each of us on this committee is aware that research in the VA medical program has been responsible for some very dramatic results. In the treatment and rehabilitation of veterans with amputations, spinal cord injuries, or sensory disabilities, we have seen advances that seemed almost impossible just a few years ago. Today, we will still have more advances demonstrated to us. I am sure, Mr. Chairman, that we will be persuaded that our support of VA's research effort is extremely worthwhile, so I congratulate you for scheduling the demonstrations and for scheduling this hearing.

Mr. Chairman, I am particularly pleased to note that a number of active VA researchers are here today and that they are accompanied by veterans who benefit from what has occurred as a result of their research efforts. I am anxious to hear from each of our guests. There are almost 200,000 veterans across the country who receive either compensation or pension as a result of the disabilities we are discussing this morning. This very sizable group has long been a very special concern of this committee. By assisting them, the Veterans' Administration and this committee also serve a much larger universe of disabled people throughout the country who have similar disabilities.

So again, Mr. Chairman, I express to you my appreciation for the hearing this morning.

Mr. EDGAR. Thank you, John Paul.

I would like to call on the chairman of the full committee, if he has any comments at this time.

## STATEMENT OF HON. G. V. (SONNY) MONTGOMERY, CHAIRMAN, FULL COMMITTEE ON VETERANS' AFFAIRS

Mr. MONTGOMERY. Thank you, Mr. Chairman. I apologize for running a few minutes late this morning. This is certainly an active subcommittee and I look forward to the demonstrations.

I congratulate the members of this subcommittee. You have certainly been busy this year, and you are working on what is best for the veteran in the areas of medical care.

Thank you for giving me this opportunity.

Mr. EDGAR. Thank you, Mr. Chairman.

Mr. Chairman and other members who are here, before you leave the hearing today, I hope that some of you will at least have a chance to ride on the omni-directional wheelchair and maybe take a look at some of the other devices.

I would also note the presence of Congressman Jim Florio, a new member of our subcommittee and full committee. It is a pleasure to have you as part of this hearing and as part of the subcommittee at this time.

Are there any other opening comments that my colleagues would like to make? Mr. McEwen?

## STATEMENT OF HON. BOB McEWEN, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF OHIO

Mr. MCEWEN. Thank you, Mr. Chairman.

There can be no better applications of technology than when it is used to relieve suffering and social deprivation. Automobile engines capable of 100 miles per gallon of gasoline are important; space technology capable of taking pictures of Mars is a giant step toward the future; and airplanes capable of flight many times the speed of sound are, indeed, amazing. But all of these and other toys of technology mean nothing if a man cannot drive a car to the corner grocery store, lift a camera to take a picture of his family, or write about flying faster than sound.

The devices before us today, and the men and women who dream of them, design them, test them, and make them available to those who need them, make all our technology pale in comparison because their devices do something the others cannot. They restore opportunity and hope to those struck down by injuries or disease and, in so doing, they elevate us all.

Mr. Chairman, when a man or woman once confined to a relatively immobile life because of lifeless legs can take their first step under their own power because of what technology can do at its best, then that truly is a great step for mankind.

I would like to recognize two Ohioans among our distinguished witnesses today, Dr. Byron Marsolais and Dr. Hunter Peckham of the Cleveland VA Medical Center. They are to be commended for their studies on functional electrical stimulation and I want to welcome them to today's hearing. I commend the Chairman and this committee on its efforts in this area and pledge my support in the weeks and months ahead.

Thank you very much, Mr. Chairman.

Mr. EDGAR. Thank you, Mr. McEwen.

Mr. Bilirakis.

## STATEMENT OF HON. MICHAEL BILIRAKIS, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF FLORIDA

Mr. BILIRAKIS. Thank you, Mr. Chairman.

I, too, have been looking forward to this hearing because I believe it will give an excellent opportunity for our subcommittee to see first hand how the needs of veterans prompt Congress to fund research which, in turn, results in concrete developments to meet some of those needs. Your involvement, ladies and gentlemen, in prosthetic research and rehabilitation must be a very rewarding experience for all of you who will be testifying this morning, although I know there must be frustrations as well.

Those of you who carry out the research that has produced advancements like the Seattle Foot must get a great deal of satisfaction from knowing that the fruits of all your efforts are significantly improving the lives of so many disabled people, both veterans and nonveterans alike. I can only guess as to what it means for those who are disabled to benefit from some new technology that enables them to push back the limits imposed by their disability. I can assure you that learning about the work that is being done and the progress that is being made will be a rewarding experience for my colleagues and me and I want to add my thanks to that already expressed. I look forward to your presentations.

Thank you, Mr. Chairman.

Mr. EDGAR. Thank you very much.

Are there any additional opening statements?

Before beginning this morning, I would like to take just a moment to thank each of the researchers and veterans who have come to demonstrate the different devices. We really appreciate the effort of the VA in putting this hearing together. It meant bringing people across the country in many cases and I just want, on behalf of the subcommittee, to thank you for taking the time to be with us.

We are first going to hear from a panel of witnesses representing the service organizations. Following their testimony we will move right to the VA and go through a series of demonstrations and discussions of the latest technologies which have been developed.

Mr. EDGAR. Let me call first our first panel of witnesses, Mr. Ellsworth Sharpe, past president of the Blinded Veterans Association; Mr. Frank DeGeorge, associate legislative director of the Paralyzed Veterans of America; Mr. Charles Joeckel, Jr., national director of services, Disabled American Veterans; and Mr. David W. Gorman, associate deputy national legislative director, Disabled American Veterans. Will you come forward at this time, please.

Let me call on Mr. DeGeorge to begin.

**STATEMENTS OF FRANK R. DeGEORGE, ASSOCIATE LEGISLATIVE DIRECTOR, PARALYZED VETERANS OF AMERICA; DAVID W. GORMAN, ASSOCIATE DEPUTY NATIONAL LEGISLATIVE DIRECTOR, DISABLED AMERICAN VETERANS; AND ELLSWORTH L. SHARPE, IMMEDIATE PAST NATIONAL PRESIDENT, THE BLINDED VETERANS ASSOCIATION**

Mr. DEGEORGE. Thank you, Mr. Chairman.

I will try to make my comments brief, but I would like to have our entire testimony submitted for the record.

Mr. EDGAR. Without objection, your whole statement will be made a part of the record.[1]

Mr. DEGEORGE. Sir, I would hope to confine my remarks to approximately 5 minutes, but I might be just a little bit over that, just so you're aware that the Paralyzed Veterans of America has much at stake in this testimony today. I hope that you will bear with us just a little bit.

Mr. Chairman and members of the subcommittee, the Paralyzed Veterans of America appreciates this opportunity to express our views regarding the Veterans' Administration's prosthetics and rehabilitation research programs. Research in this area is of critical importance to PVA's members, all of whom have experienced spinal cord injury or dysfunction. Research in prosthetics and rehabilitation holds for all severely disabled persons the greatest promise for improved physical and emotional well-being.

Mr. Chairman, it is impossible for me to begin to express to you the emotions a disabled individual feels when his or her quality of life is assisted through an advancement in prosthetics or rehabilitation research.

As we all know, the Veterans' Administration once was clearly the world's leader in prosthetic research. Prostheses and orthoses developed by the VA over the years have provided mobility for thousands of disabled veterans and have enabled many of them to pursue close-to-normal lives after the onset of disabling conditions.

One of the mandates of PVA's congressional charter is to promote research and we take our responsibilities in this area very seriously. We are proud of our organization's contributions in the area of prosthetics research.

PVA's Spinal Cord Research Foundation was created in 1976. In the past 9 years our Foundation has awarded more than $2.5 million aimed at prevention of and cure for spinal cord injury, and at care for those who have already experienced spinal cord injury. Much of this effort has been dedicated to developing and improving prosthetic devices that assist catastrophically disabled individuals.

Quite clearly, private companies would not have been willing to spend research money for the development of a device or devices that have a limited number of consumers.

Recreation for the catastrophically disabled person continues to also be one of PVA's highest priorities, and we are very pleased to recognize the VA's rising emphasis in this area.

The VA Administrator, Hon. Harry N. Walters, has stressed that competition and recreation are of special importance for severely disabled veterans and has instructed that adequate funding be provided for recreational activities.

Since PVA recognizes the importance of recreation, we, too, have dedicated funding toward this end. Today, because of our research efforts, paralyzed individuals are able to use special equipment as designated and depicted in our written testimony. I will not go into those particular projects.

As is apparent, PVA and the VA Administrator share a common understanding of the importance of many aspects of rehabilitation, and PVA and the VA have worked closely in the areas of prosthet-

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[1] See p. 51.

ics and rehabilitation research. Our mutual goal is improving the quality of life for severely and catastrophically disabled individuals. An example of this close working relationship is that both PVA and the VA are participating actively and financially in the development of uniform consensus standards for wheelchairs.

As we understand it, the VA is in the process of establishing the position of Associate Deputy Chief Medical Director for Professional Services, a position which will enable the agency to better coordinate future research efforts. The new ADCMD will coordinate both rehabilitation research and development, and the prosthetics and sensory aids service.

Mr. Chairman, we are very pleased that PVA has been able to report many positive aspects of the VA's rehabilitation research efforts. However, problems do exist that should be brought to the subcommittee's attention.

First, the VA has gotten away from its original system of a centrally controlled, nationwide system that was capable of conducting research, designing and engineering prosthetic devices, arranging for production, and training prosthetics personnel, therapists, and medical staff to best assist the user.

PVA proposes that the VA carry through on the recommendation made by the Director of Rehabilitative Engineering Research and Development; that is, establish in Washington, DC, a central rehabilitation and education and testing center. That is a very logical proposal and one that should resolve many of the problems that arise from the presently fragmented system employed by the Veterans' Administration.

The second problem deals with the VA's two rehabilitation research and development centers. One center is at Hines VA Hospital in Hines, IL, and the other at the Palo Alto, CA, VA Medical Center. These two centers already have conducted valuable research projects, and they are in place and do offer great potential for improved and expanded research. PVA feels that staffing and funding these centers should be a top priority within the VA and by the Government. However, in recent years, a larger percentage of VA funding is going to non-VA conducted projects that are similar to those that could well be performed at the two rehabilitation R&D centers.

PVA therefore strongly encourages this subcommittee and the Veterans' Administration to ensure that the centers are adequately staffed and funded. They form an important part of the VA's research effort. Furthermore, we feel that the Washington, DC, center must be established so that there will be centralized control and information sharing within the VA and between the VA and other Federal agencies.

Mr. Chairman, VA research has benefitted many of our Nation's veterans, and improvements and discoveries made by the VA have been quickly used by the larger society. In short, it has been so important to the well-being of millions of Americans that we ask this subcommittee to ensure adequate funding for the VA's prosthetic and rehabilitation research program. In short, today we are not speaking of the three R's but we are speaking of the four R's: research, recreation, reorganizaton, that lend themselves to rehabilitation.

Thank you, Mr. Chairman.

[The statement of Frank DeGeorge appears at p. 51.]

Mr. EDGAR. Thank you very much for your statement.

Mr. Gorman.

## STATEMENT OF DAVID W. GORMAN

Mr. GORMAN. Thank you very much, Mr. Chairman.

Mr. EDGAR. Mr. Gorman, the full text of your statement will be made a part of the record.[1]

Mr. GORMAN. Thank you. In that case, I will attempt to summarize my testimony.

On behalf of the 867,000 members of the Disabled American Veterans, including the literally thousands whose disabilities dictate the use of prosthetic appliances and devices, we certainly do appreciate this opportunity, Mr. Chairman, to discuss the VA's research programs on prosthetics and rehabilitation.

Mr. Chairman, before proceeding with the summarization of my testimony, may I begin by extending to you the DAV's sincere and genuine appreciation for the interest that you have exhibited in the area of the VA's research programs. On behalf of the entire membership, I would like to thank you for that.

Additionally, the DAV is of the firm conviction that within the structure of the department of medicine and surgery the research component may be singled out as one of the vital support pieces.

Mr. Chairman, research is generic to the entire medical community, most of which is conducted in the form of medical research, which is tedious, time consuming, and often the possibility of results being found are years away from finalization.

On the other hand, rehabilitation research often produces beneficial results in a comparatively short period of time. This results in disabled veterans, who must endure disabilities for the remainder of their lives, being able to utilize research findings in order to lead a fuller, more comfortable, and productive lifestyle.

The VA Rehabilitation, Research and Development Service, RR&D, is charged with the responsibility of improving the quality of life and allowing more functionally independent activities of daily living by disabled veterans through research, development, and evaluation of new or unique devices, techniques, or concepts in rehabilitation.

In fiscal year 1984, the VA's budget authority for medical research was $205 million, compared to approximately $10.8 million, or about 5 percent, dedicated for rehabilitation research. Mr. Chairman, RR&D Service is doing an excellent job, in our view, with what we consider to be inadequate and restrictive funding.

During 1981, Dr. Margaret Giannini assumed the position of Director of the VA's RR&D Service. Since that time, she has been instrumental in what we consider to be an extremely viable and enthusiastic research effort. Dr. Giannini has the gratitude of the DAV for the accomplishments that she has made over the past 3 years. However, we are extremely concerned that without adequate

[1] See p. 55.

funding, this vital service will fall behind in meeting the needs of rehabilitiation of this Nation's disabled veterans.

Realizing the tremendous impact, Mr. Chairman, for the demand of service that the aging veteran will place on the VA medical care system within the next few years, we ask that you consider that during fiscal year 1982, 6,230 amputations were performed within the VA medical system, and it can be conservatively estimated that between 80 and 90 percent of those were done because of peripheral vascular disease or PVD. The aged veteran population will only serve to increase this already statistically massive health concern in the future.

VA sponsored research efforts have salvaged many ischemic limbs and, when amputations were found necessary, made possible those amputations at a much lower and, thus, more functional level. Additionally, surgical and postsurgical techniques have been refined through VA research efforts to the point where early fitting of a prosthesis has been possible.

However, much more needs to be done, such as the development of new casting and fitting techniques for lower extremity amputations, new and lightweight materials must be found, and recreational/sport prostheses and components must be improved, developed, or refined.

Mr. Chairman, research in these areas is being done today. However, we are of the opinion that an expansion of that effort and additional studies are necessary in order to achieve the desired results in an expeditious manner.

New fitting techniques are being explored via a computer-assisted design/computer-assisted manufacture process called CAD/CAM. Basically, Mr. Chairman, I think we will see a demonstration of this today, or a limited demonstration of the technique. But as we understand it, this would permit, by the assistance of a computerized device, a lower extremity amputee to be casted and fit in more or less a traditional manner and the results and measurements fed into a computer which in turn would be able to, again with the aid of a computer-assisted milling device, turn out a finished socket in a matter of minutes. At that point the amputee could then test the socket for any pressure points that may be found and, again with the assistance of the computer, those pressure points could be found and corrected and again a new socket could be made in a matter of minutes.

Mr. Chairman, for an amputee, the most vital feature of a prosthesis is comfort. If the prosthesis is comfortable, then it is in turn functional. We feel that with the advent of this CAD/CAM process that further expansion of it is necessary.

Mr. Chairman, during September 1981 the General Accounting Office released a report on amputees and the use of artificial limbs. That report basically found that, after talking with many authorities in the field, that it was an accepted premise that amputees who wear prostheses will suffer from some degree of physical pain and discomfort. Considering the technology that we have today, we find those statements contained in that report very disturbing and, frankly, inexcusable.

During March of this year I had the opportunity to personally visit the Prosthetics Research Study Laboratory in Seattle, WA,

under the direction of Dr. Ernest M. Burgess, who was recently appointed as a VA Distinguished Physician. PRS is funded entirely by RR&D as an ongoing research project in prosthetic development. Perhaps the most widely known innovation to emerge from PRS recently is the Seattle Foot. Mr. Chairman, I am currently wearing two of these feet and can personally attest to their excellence over any other foot that I have ever worn in the past. They have permitted me for the first time, since losing my limbs in Vietnam in 1969, to actually be able to run for short distances with a relative degree of comfort.

Without meaning to sound overly dramatic, Mr. Chairman, an amputation does change one's life, and the devices that are developed through the VA's research program such as the Seattle Foot likewise change an amputee's life.

Unfortunately, only a few of these feet have been issued to veterans at this point. We are hopeful that this particular project will receive the funds necessary to make the Seattle Foot the optimal foot for the veteran amputee and be provided to that veteran.

Earlier, Mr. Chairman, I alluded to the level of funding for the VA's medical research service. Not to be misunderstood, the DAV supports the VA efforts in this area. However, they have not, in our estimation, been confined to disease or disabilities that are entirely common or prevalent to the disabled veteran.

There is no doubt as to the importance of medical research. However, how do we explain to an elderly veteran that no new developments are underway to make lightweight prostheses that would enable him to walk with the least degree of effort, while at the same time research money has been provided to study decreased eyebrow-raising by emotionally disturbed veterans during an interview situation? Or how do we explain to an amputee, that can't obtain a comfortable fitting prosthesis, that computerized fitting may be possible in the future if funds become available, when the VA has funded research to determine the effects of high and low nicotine cigarettes on male beagle dogs? Or how do we explain to a young, enthusiastic amputee who wants to participate in as many sports and recreational activities as possible that such prostheses have not yet been perfected due to the lack of adequate funding, while research regarding the learned taste aversion in man has been done by the VA medical research programs.

Mr. Chairman, not only could I not answer those questions, but I would not want to be placed in a position where I would ever be asked them.

Mr. Chairman, the VA's involvement with prosthetic research basically began following the end of World War II with the birth of the Prosthetics Research Program. With the enactment of legislation over the years, it was possible for the VA to establish itself as the world leader in the field of prosthetics. Many new developments, innovations, and improvements have been made in the field of prosthetics following World War II by the Veterans' Administration.

However, during 1973, following the completion of a major reorganization that totally restructured the entire VA prosthetic program, a change for the worse occurred. Prior to 1973, the Prosthetic and Sensory Aids Service provided for clinical prosthetic services

delivery, the Research and Development Service managed the R&D contract program, and the Education and Training Division conducted ongoing education and prosthetic programs.

As a result of the 1973 reorganization, the Prosthetics and Sensory Aids Service was placed under the direct jurisdiction of the Assistant Chief Medical Director for Professional Services, the research component was transferred to the ACMD for R&D, and the Education and Training Division was the responsibility of the Assistant Chief Medical Director for Academic Affairs.

This has caused, in our opinion, a fragmentation of the VA's prosthetic activities which still exists to a degree today. We believe that the original reasons for consolidating the prosthetic services under a single program are as valid today as they were in 1945.

Mr. Chairman, we have requested the Administrator to consider a reorganization within DM&S to once again form a separate and distinct service that would place all rehabilitative services under the jurisdiction of a single and newly created Assistant Chief Medical Director for Rehabilitation, Prosthetic Services, and Associated Research and Development.

To fully illustrate the DAV's position on this subject, Mr. Chairman, and offer suggestions on how it may be accomplished, I would like, without objection, to submit for the record some various correspondence that we have forwarded to the administration and have received from the Administrator regarding this.

Mr. EDGAR. Without objection, your whole sheaf of letters will be included in the record at this point.

[The information appears at p. 59.]

Mr. GORMAN. Mr. Chairman, we would also request that following the subcommittee's review of this submitted material, and if you agree with our proposal and feel it has merit, that you pursue this matter with the Administrator. Additionally, I would ask that the subcommittee consider the feasibility of legislative action to create such a slot of Assistant Chief Medical Director.

The VA currently operates a Prosthetics Evaluation Testing and Information Center known as PETIC. PETIC was formerly known as the VA Rehabilitation, Engineering Center, or VAREC, and is charged with the responsibility of providing veterans, on a nationwide scale, prosthetic and sensory aids; performing tests on new devices in the prosthetics field; and evaluating and testing commercially available devices for handicapped veterans. PETIC also serves as a focal point for gathering and disseminating prosthetic and orthotic devices, as well as sensory aids to VA field stations.

Mr. Chairman, PETIC has been a source of controversy for many years. Indeed, it has been and continues to have problems in fulfilling its mission of serving disabled veterans. We are now forced to raise the question: What exactly is the function of PETIC?

We know it has been designated as a national referral center for veterans who present difficult prosthetic and orthotic problems. However, virtually all veterans seen at that center reside in the immediate metropolitan New York area.

Mr. Chairman, we have presented our views on this subject to the Administrator and asked specific questions regarding PETIC. As of yet, we have not received a satisfactory response.

Contained in the material that will be submitted today for the record are our views and concerns regarding the operation and the function of PETIC. As with the issue of reorganization, we would respectfully request the subcommittee review this issue, also.

We have offered the following recommendations in regard to PETIC, Mr. Chairman. First, PETIC should be relocated outside of the metropolitan New York area. We suggest that it be reestablished at a location that possesses the capabilities to provide direct patient care, direct prosthetic services, and a research component. Additionally, an active affiliation with not only a medical school but a school of engineering and a university with an active prosthetic training program would also seem vital.

Mr. Chairman, the Hines VA Medical Center in Chicago would seem to be a reasonable and logical choice. In addition to all the components previously mentioned, Hines also has the added attraction of having a VA-sponsored RR&D center.

Mr. Chairman, again I want to thank you for allowing us this opportunity to present our views on this most important subject. Thank you.

[The statement of David Gorman appears at p. 55.]

Mr. EDGAR. Thank you very much for your testimony.

Mr. Sharpe.

## STATEMENT OF ELLSWORTH L. SHARPE

Mr. SHARPE. Mr. Chairman, members of the committee, I'm sorry I was late. I had problems getting in the building. I'm glad the security is good.

The VA has long been a leader in the development of prosthetics and rehabilitation techniques in the field of blindness. However, we believe now they are losing their leadership and they haven't given much priority in this area.

Last year $150 million was spent in this area in general, but less than 1 percent of this was spent for blind rehabilitation or blind research. Of this research money that was spent, 21 of the 25 were in areas such as interocular implants, and these were said to be done for the blind community. Obviously, if you can use an interocular implant, you're not a blind person.

However, priority in general seems to be part of the problem; $4 million worth of projects were approved by the VA; however, for lack of funding by the Congress and the President, these were not approved.

What are the reasons for this low priority? I have two ideas of my own. One of these is that blindness is not a life-threatening matter and it lacks priority on that basis. Also, people who work for the blind in prosthetics and rehabilitation research are not medical doctors. Of course, medical doctors control the purse strings to those who are sympathetic.

Perhaps the BVA, itself hasn't pushed hard enough. We have been waiting for the technology to develop and now we believe it has developed to where we can start taking advantage of it. In 1983, again less than 1 percent of the budget for prosthetics was allotted to aids for blinded veterans. The VA, however, did try in

1985 to get funded 50 reading machines for blinded veterans. However, OMB put a stop to that and cut the funds for 1985.

Another common area is that it seems to take too much time for the device to get to the veteran after it has been developed. We're not sure, but we believe part of the VA regulations are part of that. This is a moving technology and we realize that if you wait awhile this, too, will be obsolete. But there is a need now for aids for people in everyday living.

The VA itself is not wholly supportive of us at all times. For instance, in 1982, the Chief Medical Director's office promised centrally funded VIS teams throughout the country. We already have begun this effort, and 36 more were promised to us in 1983, 1984, and 1985, 12 in each of these years. Well, halfway through 1983, when I was president of the Blinded Veterans Association, we again approached the offices of the Chief Medical Director and noted that a year had passed on and no other positions were appointed. We were given 4 positions that year and told we would get 12 in the next 2 years and 8 a year after that. Well, the VA itself chose not to put in their budget for 1984 and 1985 centrally funded VIS coordinators.

Now, VIS coordinators are the Visual Impairment Services, and it was found that due to the isolation of blindness and research in the early sixties, that this was needed in order for blinded veterans to take full advantage of services offered to them by the Veterans' Administration.

Also, a much needed center for blind rehabilitation is in Puerto Rico, where there is somewhere between 300 and 1,000 blinded veterans, with no rehabilitation, either civilian or military. The Senate, we believe, through some other kind of hassle with the VA, did not approve this center along with other things that are going to be done in Puerto Rico.

The VA is currently going over and reorganizing their rehabilitation and prosthetics research area. However, even down at the grassroots level they don't realize that even four of their larger centers do not even have prosthetic chiefs. So it hasn't been given a lot of priority.

This is one area that I am quite familiar with. I talked earlier about the VA regulations and that seemed to include provisions for rapidly growing technology. In talking of low vision personal computers, these have recently been on the market. The VA doesn't seem to be able to fit the purchase of these in their budget. Four years ago I was a research engineer with NASA and I was competitive with the other people in the programming area—I did other things besides computer programming, but that was part of my job. When the inneractive computers came out with their television screens, I was unable to use this type of device, so I still had to use the punch cards. It looked like raises weren't going to come very fast until something straightened out, so I did change agencies. However, today there is a low vision and a talking computer, or you can get both in one device, and that is available. Yet the VA still hasn't chosen to give these to veterans.

I would like to thank you very much for this opportunity.

[The statement of Ellsworth L. Sharpe appears at p. 75.]

Mr. EDGAR. Thank you very much for your testimony.

All of you have given excellent testimony to the committee, and you point out your concern about the size of the VA budget as it relates to prosthetic and rehabilitation research efforts. You talk about the fact that in a couple of areas the VA's leadership has slipped, and is not as oriented toward providing help as it once was in certain areas, and you talk about the need for better coordination and the establishment of an Assistant Chief Medical Director for Rehabilitation Research. You mention the possibility of a center of excellence to try to coordinate some of the efforts in this area.

I think, while your testimony was critical, all of us would have to say that there are devices and pieces of equipment which have been developed with the help of the VA which have been great steps forward. We are going to see in a few minutes some of those devices. While we will look at those devices with a great deal of appreciation for their development, it also is important to recognize that we have oversight responsibility in terms of keeping the pressure on the VA to continue their research and their rehabilitation efforts as creatively as they can, and whether we exercise responsibility to do that legislatively or through oversight hearings will depend on the issue.

So I want to thank each one of you for your testimony today.

I yield to my colleague, John Paul Hammerschmidt.

Mr. HAMMERSCHMIDT. Thank you, Mr. Chairman.

I, too, want to thank you, Mr. De George, Mr. Gorman, and Mr. Sharpe for your excellent testimony. You brought us very comprehensive written testimony and certainly each of you made a good verbal presentation to the committee.

We have a lot of time pressures this morning. There is a joint session that starts in about 10 minutes and I know we have some important VA witnesses to follow you, so I am going to forego any questions. But we do very much appreciate your testimony here.

Mr. EDGAR. Are there questions of this panel of witnesses? We appreciate your taking the time to be with us this morning.

Let me now ask Dr. John A. Gronvall, Deputy Chief Medical Director of the Veterans' Administration, to come forward and to bring with him any of his staff that he wishes to.

Welcome. It is good to have you here with your voice back. At our last hearing with Dr. Sabin, you were unable to speak with any clarity. We were thinking you might have to have a voice implant, and I'm glad that wasn't necessary. We are really looking forward to hearing from some of the people in your service who have done some exciting things in the area of research. We will let you proceed. Dr. Boren, it's good to have you here again this morning.

**STATEMENT OF JOHN A. GRONVALL, M.D., DEPUTY CHIEF MEDICAL DIRECTOR, DEPARTMENT OF MEDICINE AND SURGERY, VETERANS' ADMINISTRATION; ACCOMPANIED BY HOLLIS G. BOREN, M.D., ASSISTANT CHIEF MEDICAL DIRECTOR FOR RESEARCH AND DEVELOPMENT, DEPARTMENT OF MEDICINE AND SURGERY, VETERANS' ADMINISTRATION**

Dr. GRONVALL. Thank you very much, Mr. Chairman. It is a delight for us to be here and a pleasure for me to be here with my

voice. It is a particularly difficult problem to be a mute witness at a hearing, so I appreciate your patience.

The Veterans' Administration is delighted with this opportunity that your committee has given us to present to you in these three hearings some of the work going on in our research program, and we thank you very sincerely for the strong support that we have had from your committee for our research activity.

As you well know, the veteran population that we serve includes more than 150,000 amputees, more than 50,000 spinal cord injury victims, more than 180,000 veterans with hearing impairment, and more than 60,000 visually impaired or blind individuals. These challenges continue to grow, actually, as aging complicates the disability or, in fact, brings on wholly new disabilities, and so today we will present a sample of the work that has gone on in the some 97 rehabilitation research projects funded with our $10.9 million of research support.

Most important, we pledge that this work will continue as we develop new aids and devices to assist those with a disability, in living with that disability in a better way, as we also search for new ways to completely overcome disabilities and even in some cases new ways to prevent disabilities in the first instance. So we are delighted to be here and I will turn to Dr. Boren to introduce these several presentations.

[The statement of Dr. John Gronvall appears at p. 76.]

Mr. EDGAR. Dr. Boren.

Dr. BOREN. Sir, it is a pleasure to be with you this morning.

I would like to start off by introducing Dr. Larry Leifer, who is Director of the Rehabilitation Research Center in Palo Alto, CA. Dr. Leifer has two demonstrations which he will make, first on the robotic arm and, second, on the omni-directional wheelchair.

Dr. Leifer.

**STATEMENT OF LARRY J. LEIFER, DIRECTOR, REHABILITATION RESEARCH AND DEVELOPMENT CENTER, VAMC, PALO ALTO, CALIFORNIA; ACCOMPANIED BY MICHAEL VAN DER LOOS, TIMOTHY HERITAGE, ROBERT SMITH, DOUGLAS SCHWANDT AND PETER AXELSON**

Dr. LEIFER. Thank you, sir.

Mr. Chairman, members of the committee, my name is Larry Leifer and I am the Director of the Rehabilitation Research and Development Center of the VA in Palo Alto, and a professor of mechanical engineering and neurology at Stanford University.

With your permission, I would like to depart from the prepared text in the interest of speed and get directly to the demonstrations.

Very briefly, since our inception in 1978, we believe that we have developed a balanced program of basic, applied, and market research for the production and development of products, assistive devices, for the disabled.

Our productivity has recently been summarized in a progress report which covers these years, and we would be happy to share it with you. It's hot off the press. This document contains abstracts on over 32 projects, a tabulation of 240 papers, 235 scientific presentations, during this time.

Mr. EDGAR. Without objection, we would like to have a copy of that for our record.

[The progress report appears at p. 82.]

Dr. LEIFER. Today we would like to focus on deliverables. In the addendum to the testimony there are lists of 15 products or methods which are either on the market or clearly in the pipeline for arrival on the market. Four of those devices have been brought forward to you today, and I think, in part due to the weather, Dr. Boren will have all four of them here in the testimony today.

First is the robotic aid. This is a manipulation device that has been made available by the advent of microcomputer technology and advances in the theory of robotics. The objective is simply to augment the living and vocational capacity of severely disabled veterans and elderly individuals who also need these devices but don't typically think of themselves as disabled.

I would like to introduce to you Mr. Michael Van der Loos, the project engineer who will assist in the demonstration, and Mr. Timothy Heritage, a disabled veteran who was initially a patient in the spinal cord injury unit in Palo Alto and has subsequently worked with us in the development of this device.

While they bring the device to the front, I will say a little bit about its key features.

Most importantly, the system contains the capacity to adapt to its environment. It can adapt to the human who uses it, principally through the channel of voice command and voice recognition. One speaks to this machine and it speaks back.

Unfortunately, with the vagaries of transportation, this particular feature of the system was damaged. We will simulate it, however, and you will see accurately its general nature.

The system also possesses sensors that allow it to feel its environment and in an important concept it is a machine that begins to know who uses it and where it's being used.

Tim, would you show us something of the voice command of this operation.

Mr. EDGAR. If you don't mind, the members may want to come down a little closer.

Dr. LEIFER. We can hold for a moment.

[Robotic aid demonstration.]

We will now conclude that element of the demonstration. We have two more pieces we would like to show you. Unfortunately, it requires that you go back to your seats.

The key feature there, again to reiterate, this is the first of a kind device. In its attempt to adapt to the environment, it takes on a serious technical challenge. The practical outcome is, however, that the device could be used anywhere and could be taken with the individual wherever they choose to work or live.

Mr. EDGAR. Before you go on to the next device, I might indicate that some of us visited Palo Alto and saw that device in its home setting, where it hadn't been bounced on its head, so that the voice command worked. The gentleman working the device was preparing some materials for breakfast and was practicing moving saltshakers and materials. I think it is important to mention the uses of such a device.

Dr. LEIFER. With your permission, we would show a 4-minute videotape segment that would illustrate that more complex scenario. The point here is that these motions which you saw being relatively slow, but under the command of the operator, can be built up into a much more complex scenario. In this case we have a 4-minute segment that shows a meal being prepared and served.

Could you start that tape, please.

[Video presentation with narration as follows:]

NARRATOR. This is Tim's first encounter with a robot, but keeping a watchful eye on the whole situation were two of the system's designers. They have been working for a couple of years with a robot, and a $45,000 standard off-the-shelf arm commonly used by industry——

Mr. EDGAR. Can we hold for a second? Is it possible to stop it and turn the monitor around so that the audience can see?

Dr. LEIFER. Our second monitor seems to be down. We've had trouble with that.

Mr. EDGAR. Why don't we just turn this monitor around so that everybody can see.

Dr. LEIFER. Certainly, whomever you would prefer to see it.

[Video presentation continues.]

NARRATOR. . . . and from the training to understand Tim's commands, with the help of a voice-recognition computer. By repeating the robot's list of 52 commands, Tim teaches the robot how the words sound coming out of his own mouth. For each command, the computer makes and stores a voiceprint in its memory. Now Tim is the person in control.

At first, Tim has to use the robot in its slow, step-by-step mode, and getting a cup to his mouth takes almost 2 minutes. Later he will program the robot to remember this task.

Here is how the task looks when it is preprogrammed. Taking a drink is just the beginning. One week later, in response to a challenge from the discoverer, the robot is set up in a kitchen environment. The question: Can Tim prepare a meal? Those code words correspond to arm motions which are laboriously programmed using step-by-step commands.

The beauty of programming is that it saves time on activities that Tim would have to do every day if he was living on his own again. The designers of this robot hope to have it mounted soon on a voice-controlled mobile base. Tim savours the thought of having one of his own as he waits for his dinner. In just one week, we have gotten a good taste for the potential of robot helpers. That has improved his outlook on what it is to be a quadriplegic.

Mr. HERITAGE. At the very beginning you think this is it, you know. But that's totally wrong, because it is not. All you have to do is find out what you can do, find out what your limitations are, and change them.

[End of video presentation.]

Dr. LEIFER. Thank you.

We have one last, very brief, demonstration. It lasts about a minute, and it is not the one you would expect. But a very important component of this work comes from the field of artificial intelligence. In the pursuit of artificial intelligence, one is generally trying to understand languages for telling computers what to do. In this case we have the problem of telling the computer how to tell an arm how to move. In pursuit of that, we have been studying ballet. Ballet is one of the only fields of human endeavor where control and description of motion is explicitly dealt with. Out of that, we would like to show you a 60-second excerpt of motion for the arm. The objectives are esthetic, scientific, the pursuit of understanding of the language of motion, and they are technical, how do you create a machine that will move efficiently and elegantly.

At the last minute, of course, the music decides to conk out.

[Demonstration.]

Dr. LEIFER. Thank you very much. It is clear that when the machine lost its voice, it lost its ability to sing as well.

That concludes this demonstration, perhaps with the summary comment that the cost of these machines will be approximately that of an automobile. There is no reason that they should cost more than that when they become broadly available.

The second project we would like to demonstrate for you is called the ALEXIS, the omnidirectional wheelchair. This is a mobility aid that has been made possible by the balanced application of mechanical, electronic, and programming skills to integrate several different important features into what we hope will be a new class of personal vehicle.

The objective is simply to provide wheelchair users with the same degree of agility as ambulatory individuals have in moving about cluttered environments in the home and office.

The most visible feature of this system is its ability to move forward and backward, left and right, and to pirouette on its central axis.

While Bob Smith, the demonstrator and principal developer, continues to demonstrate motions of the system, I will comment on some of the key features.

Again, as in the robotic aid, the central element is micro-computer technology that allows it to adapt to the driver and to adapt to its environment. Its structure is unique in the use of composite plastic materials equivalent to those used in advanced fighter aircraft. They allow the vehicle to have a suspension system unlike other wheelchairs built into its framework. This also provides for vibration damping.

A new, high efficiency power controller causes this vehicle to be able to move with an efficiency of 50 percent from battery to motion, compared to 20 percent in most electric-powered vehicles. It is entirely modular in design and that facilitates both low cost manufacture and serviceability.

The cost of this system will be equivalent to that of other electric powered wheelchairs. It is currently targeted to arrive on the market in January 1985, by the Intex Corp., at a projected price of $6,000.

That concludes the second device.

Mr. EDGAR. Would it be possible for members to have a chance to try it?

Dr. LEIFER. Absolutely.

I do want to caution anybody who tries it that this is an experimental vehicle.

Mr. EDGAR. I have driven it before.

Dr. LEIFER. That's why we were so quick to say yes.

Mr. EDGAR. There is not quite enough room to get up to full speed, is there? It's like working a joystick on a regular computer.

Dr. LEIFER. The joystick has some of the properties of a game controller in computer environments or computer graphics. The freedom of motion is somewhat like that of a helicopter, in the sense that you have many motions.

One of the things that the microcomputer contributes to it is some operators will not be able to use all of its capability; therefore, the machine can adapt to that operator and restrict its freedom of motion to correspond with the capability of the user.

Thank you very much for trying it.

Mr. BILIRAKIS. What's the status of production and what's the cost? The cost you said was $6,000, I believe.

Dr. LEIFER. I am not sure I'm hearing you. Production is scheduled for January. The Intex Corp.'s estimated introductory price is $6,000. That's about comparable to a medium-level, electric-powered wheelchair.

Mr. BILIRAKIS. How available will it be for veterans?

Dr. LEIFER. The initial project plans call for a production run of 500 for distribution in the bay area, so that the test and development cycle can be carried through that first production cycle, with an estimated run of 1,500 in the second year.

Mr. EDGAR. Is that mostly for indoor use, in terms of office complexes and that type of thing?

Dr. LEIFER. Yes. We aren't saying it can't be used outdoors, but we would like its initial use to be indoors, that's correct.

In a sense, its agility is most important in crowded environments. Those tend to be the ones that we build for ourselves in offices and homes. As you know, many homes must be modified structurally to allow electric-powered wheelchairs to get into bathrooms, into kitchens, into bedrooms even. This vehicle should allow a house to be used without modification, a major savings in and of itself.

Mr. EDGAR. Are there any questions by any of the members on these devices we have seen so far?

The one question I have on this device, was the VA always happy with it? I heard a report that the VA didn't think it would work.

Dr. LEIFER. I think that wasn't only a VA perception. I mean, some members within the organization would be skeptical. I would have to admit that I was very skeptical when I first saw the concept presented to me. We subjected it to one of the most rigorous reviews I have ever done. We had 30 professional people come and examine it technically, could it do what it promised, and then we had quite a few disabled users come and look at a model of it and say, if we could build a full-scale model, would this be desirable. That was very clear generally, that yes, it would be desirable.

We then went through a period of evolution on it, where the general acceptance level kept creeping up. I think with this particular model we have clearly passed the threshold in its acceptability and its proof of capability. Even though it has what many people consider to be a no, no in vehicles—it has three wheels—it is actually the essence and elegance of this vehicle that it has three. The presence of an on-board computer can allow that vehicle to always operate within its safe operating domain. If you try to go forward full speed and crank a full right turn—and we know from understanding the vehicle that that would cause it to tip over—the vehicle would not let you do it. It would slow down and then initiate the turn. So there is some intelligence in it. That allows us then to make a very small footprint and let's us get around inside.

It's an uncommon scenario. If you come up with something a little radical, you're going to have to go through a period of time where we know that heavier-than-air planes aren't going to fly and things of that order.

Mr. EDGAR. How did you get the company that is actually going to produce them into that business? Were there competitive bids? How was that process devised?

Dr. LEIFER. That's an interesting story, a rather long and complex one. I don't think I would try and give all of it now, except they were introduced to it, in part, out of a marketing research effort that we were doing in-house. I mentioned we do basic, applied, and market. One of the individuals involved in that had made contact with this company. The company was looking for a product in the medical market, in the rehabilitation market in particular. When the president and vice president came in and looked at the prototype of this vehicle in particular, they simply were enthusiastic. There was no problem to sell them.

It is perhaps of further interest to know that this company raised a million dollars in venture capital to build the first production model—that is to build the next generation—and that they have scheduled $5 million additional to put it into production. That sum of investment equals approximately our net budget for the last 5 years. So as you move to market, things get rather serious.

Mr. BILIRAKIS. Would the chairman yield?

Mr. EDGAR. I yield to the gentleman.

Mr. BILIRAKIS. Sir, how long will it stay charged?

Mr. SMITH. About 4 hours continuously.

Mr. BILIRAKIS. About 4 hours.

Dr. LEIFER. Would you like to comment on the batteries and the power train?

Mr. SMITH. The machine has a rather more efficient power operation device than a conventional wheelchair, Mr. Chairman and members. As a consequence, it is able to wring more life out of a given set of batteries. The battery life in this machine in our experience, in driving it around and demonstrating it, has been that you can keep it operating and moving for about 4 hours continuous, which is roughly typical for a conventional wheelchair. This uses smaller than normal batteries.

Mr. BILIRAKIS. Now, as to the scenario on the funding, the money end of it, what is it going to cost the Veterans' Administration? Is the figure $6,000?

Mr. SMITH. That would be the suggested retail price of the product.

Mr. BILIRAKIS. Would that be paid for by the veteran, or paid for by the Veterans' Administration and furnished to the veteran? How is that going to work?

Mr. SMITH. That would be determined by whether the Veterans' Administration approves this product for purchase by the Veterans' Administration.

Mr. BILIRAKIS. Would it be made available free of charge to the veteran who would qualify?

Mr. SMITH. Yes, sir.

Mr. BILIRAKIS. That's the contemplation?

Mr. SMITH. Yes, sir.

Mr. BILIRAKIS. Thank you.

Thank you, Mr. Chairman.

Dr. LEIFER. I would stress this is entirely a private corporation producing the device for retail, and any of the subsequent purchasing procedures would come into play.

Mr. EDGAR. Let me ask one additional question about the charging. Let's suppose someone was using that in an office setting and they were using it to be mobile on several floors of an office complex over 4 hours. When they were stationary at their desk, let's say doing a particular chore, can they plug it in?

Mr. SMITH. Yes, they certainly could, Mr. Chairman. I should also stress that that 4 hours of operation is not 4 hours time during the day. It is 4 hours of actual motion. For example, not many of us actually spend 4 hours a day walking, and that would be the equivalent activity.

Mr. EDGAR. My son's Radio Shack car is battery-operated, remote control cars don't last that long.

Dr. LEIFER. Of interest on the charging front, we have a project on the shelf right now, looking to bring it out, which has to do with noncontact charging. At your work station there could be an RF cable or RF antenna built into the vehicle, that could be a receiving antenna, and you could charge any time that you're sitting at your work place without any connective fuss. It has been demonstrated in the golf cart market.

May we proceed?

Mr. EDGAR. Please proceed.

Dr. LEIFER. The next device we would like to demonstrate for you is called the "sport bike". Fundamentally, it is a challenge to the notion that paraplegics and other wheelchair users can't use bicycles. The objective of this project is integrative recreation, therapeautic, and competitive biking. It is being demonstrated for you by Douglas Schwandt, one of the principal developers of the device.

A key feature of it is accessibility, in that an individual can transfer from their wheelchair to the bicycle by the fold-down of the crankcase at the front of the vehicle. Will you be able to demonstrate that, Doug?

Mr. SCHWANDT. Yes.

Dr. LEIFER. While there are other recumbent bicycles on the market, none of them have this feature which is important to the wheelchair user.

Another feature of this system is the soft sling seat, again not available in other recumbent bicycles. Certainly none of the other recumbent bicycles are front cranked.

The side wheels you see allow the vehicle to be kept upright at zero velocity. This is important if the vehicle is going to be used in an elevator and in other crowded environments up and down narrow ramps. The intention is that this vehicle could get you door to door. We don't advocate that it's a replacement for the wheelchair, but you can travel on this vehicle at 12 miles per hour. It has caliper brakes equivalent to any other bicycle. It has bicycle gearing. It has the performance of a bicycle. Many of us bicycle to work.

This vehicle will cost about the same amount as the sport wheelchair. The current estimated price on the market is $1,700. It has been available since October 1983, by Recreational Mobility, Inc.

Are there any questions you would like to ask concerning this device? We would be able to demonstrate it a little more vigorously either in the hallways or outside in this afternoon's demonstration.

Mr. EDGAR. I just want to apologize to the creators because I almost wrecked it when I was out in Palo Alto riding around in the streets. But I enjoyed the opportunity to get on it and have a feel and a sense for its capabilities. I want to commend you for your efforts with it.

Let me just say to everyone that many of the Members are over at a joint session that was scheduled after our hearing was scheduled, and that is why we have a small number here. But some may want to take a look at that in the hallway later to see it at a little faster speed.

Dr. LEIFER. We certainly would be pleased to demonstrate it.

Mr. BILIRAKIS. This is designed to be outdoors; is that right, sir?

Dr. LEIFER. Primarily outdoors. Really, it's a one-to-one equivalent to a bicycle that the ambulatory would use.

Mr. BILIRAKIS. So if a veteran had a choice, why would the veteran choose this over the motorized wheelchair? Would it be because this is designed for outdoors and the other is not?

Dr. LEIFER. Well, let me stress that it is recreational and physically therapeutic. It is an exercise opportunity.

Mr. BILIRAKIS. I see.

Dr. LEIFER. Very often, as we will see from this and the next project, competitive recreation is a very powerful physiological and psychological performance domain for the veteran.

Mr. EDGAR. Would it be much more likely that a veteran would have this as kind of an extra item to use for recreation as opposed to the wheelchair, which would be a mandatory use in an office setting?

Dr. LEIFER. Yes. We are increasingly seeing multiple wheelchair possession by wheelchair users.

Now, we have one additional project we would like to show to you. It is called a "sit ski". It comes fundamentally from the challenge of the notion that disabled people can't ski. The objective is integrative recreational, therapeutic, and competitive downhill skiing. It is being demonstrated for you by Peter Axelson, its initial creator and a member of our design staff.

The shape that he is showing to you on the bottom is fundamental to its maneuverability and capability. It has metal edges like your own downhill skis. It has a rocker contour that allows quick mobility and change of speed and direction. It also is made of composite materials which allow it to be light and strong for protection, and the cover you see on it is essentially the equivalent of the upper half of your boot if you ski. It provides a very close, very tight fit so that the user's body is snugly, safely, and controllably in the sled. I almost said shoe because it is equivalent to a shoe in skiing, the importance of having good body contact. I think that is enough with that.

Peter would like to make one or two comments regarding the evolution of this device, and then, in the absence of snow—we were

sure we would have snow here in May—we would like to show a very brief videotape segment that gives you a sense of the action and excitement when this device is used.

I would like to point out before you start, Peter, that as a result of the creation of this device, there are now slaloms, giant slaloms, and downhill events in the Handicapped Ski Championships and Olympics of the world.

Mr. AXELSON. Mr. Chairman and members of the committee, I would just like to communicate to you the desire that I have always had to be involved in sporting and recreational activities while I was at the U.S. Air Force Academy, and that I am very grateful to the Veterans' Administration because I received very excellent rehabilitation at a VA spinal cord injury center. I was also fortunate to obtain vocational education benefits and was able to finish my degree at Stanford University.

However, I have experienced somewhat of a frustration in trying to find ways in which I could recreate and continue my desire to be involved in sporting and recreational activities, so I took it upon myself as a designer to apply rather simple technologies to incorporate ways to facilitate recreational activity.

I think one of the main things I have been real concerned about are integrated types of recreational activities. Not everybody likes to compete, and the opportunity of the sit-ski is that it enables someone with a disability to ski with their family and friends again. I think that is really an important thing. The same thing with the hand bike. People can now go out and recreate with their family and friends again as well as compete against one another.

So with those comments, I would just like to share the development of the Arroya. Like Dr. Leifer explained, with the edges and control surfaces, it is maneuverable to a very high degree and allows you to integrate into a downhill ski area along with the other skiers, so that you are recreating with family or friends or competing.

Thank you, Mr. Chairman.

Dr. LEIFER. We would like to conclude then with a very brief videotape segment showing this device in action. Peter, if you would like to narrate it, I believe there is no narration.

[Videotape presentation.]

Mr. AXELSON. This was filmed at the National Handicapped Ski Championships in Squaw Valley, California. A number of the various skiing techniques are being demonstrated here. Like I said, to integrate into a ski area, the device has to be chairlift compatible, so whatever sport you are trying to participate in, it is very necessary that you fit into all those elements.

Here you see a skier on the downhill, where they are required to wear helmets. Of course, not all turns are successful. You don't have as far to fall, though, either. [Laughter.]

I might point out that in the National Handicapped Ski Championships this year, in Jackson Hole, Wyoming, we had over 150 competitors compete, just to vie for spots in the national competition. The top 30 competitors competed in the slalom, giant slalom, and downhill events.

[End videotape presentation.]

Mr. AXELSON. Thank you very much.

Dr. LEIFER. Mr. Chairman, I would like to point out that the device is essentially equivalent to that of ski equipment for anyone

else and costs approximately $1,200. It has been available since October 1981, from Beneficial Designs, Inc.

I would like to conclude with one brief statement, that I believe—if I may put on my academic hat for a moment—that the Veterans' Administration should be congratulated on its perception of and willingness to support advanced technology and recreational activity. They are relatively unique in that. None of the other agencies of this country have become involved in those areas.

Mr. Chairman, thank you very much for your time.

[The statement of Dr. Larry Leifer appears at p. 80.]

Mr. EDGAR. Thank you for the demonstrations on all of those devices. We appreciate it.

Dr. LEIFER. I neglected to point out that we have handouts describing each of these devices if you want more information.

Mr. EDGAR. Thank you very much.

I will now turn it back to Dr. Boren for our other demonstrations.

Dr. BOREN. Our next demonstration, Mr. Chairman, is by P. Hunter Peckham, Ph.D., who is a co-principal investigator at the VA Medical Center in Cleveland, OH. This will be the first of two presentations on functional electrical stimulation. We have heard so much about this. This will be the functional electrical stimulation of the upper extremities. Dr. Peckham.

**STATEMENT OF P. HUNTER PECKHAM, COPRINCIPAL INVESTIGATOR, VAMC, CLEVELAND, OH, ACCOMPANIED BY GEOFFREY THROPE, REHABILITATION ENGINEER, AND JAMES JATICH**

Mr. PECKHAM. Mr. Chairman, I have presented a prepared statement, which I would like to enter into the record.

Mr. EDGAR. Without objection, your full statement will be made a part of the record.

Mr. PECKHAM. Thank you very much.

The work that we would like to talk about today from the Cleveland VA Medical Center represents a development of using low levels of electrical current to activate muscles which are paralyzed. These are muscles that the person cannot voluntarily control but where a low level of electrical stimulus, pulses of electrical current, can be used to activate the muscle. When the muscle contracts, the objective is to harness that movement so that the patient can regain some functional activity.

With my colleague, Dr. Marsolais, who is working in lower extremity applications, and our group, which is working in the upper extremity applications, we would like to demonstrate some of this work to the committee.

The way that we have approached this very, very difficult problem is to introduce into the muscles small wire electrodes, which are these fine coils which I can pass around to members of the committee. This small wire is used to introduce the electrical stimulus specifically to the individual muscles which we are trying to elicit the response from. These electrodes can remain in through the skin for periods of years. Doing this, we are able to apply electrical stimuli very precisely to obtain defined motions.

Now, when we are doing these applications, it is quite important to be specific in grading the strength of the contraction and focusing the electrical stimulus.

My colleagues here are going to demonstrate in a moment a device which enables him to activate the muscles using electrical stimulus. I will just go through a short scenario here which will show you what we are demonstrating.

Mr. Jatich, who I will introduce in a moment, is wearing beneath his clothing a device like this. It measures the movement between his chest and shoulder. As he pulls his shoulder forward and back, it controls the electrical stimuli that go to the various muscles. We are activating four muscles in this case. This movement is what is used to govern the electrical stimulus, to govern the movement of his hand.

I will pass this around, and also this small little stimulator device, which I will take the cover off, which has a small little microprocessor unit in it, for your examination. At this stage we have over 30 patients who have worked with us in the development of these systems, and 8 who are now currently involved in evaluation of these devices outside of the hospital environment.

Our long-term objectives are to remove the electrodes that are going through the skin, so that the electrical stimulus can be controlled with a radio frequency signal, electro-magnetic waves which are transmitted through the skin to implantable devices. This will eliminate the need for the wires going through the skin and which are certainly a potential source for irritation and inconvenience and require some attention by the patient or his attendant.

I will pass around a totally implantable device which you see here, which is ready now, after this is welded on to the top here, to be implanted into the body. We are presently involved in evaluation of that with animals.

Now, at this stage I would like to introduce my colleagues. On your right is Mr. Jim Jatich. Jim is a C–5 level quadriplegic who sustained a spinal cord injury in a swimming accident in 1977. Since that time he has been working with us in developing various aspects of this, and for the past month and a half he has been working with evaluating this system.

The other gentleman on your left is my colleague, Geoffrey Thrope, who is a rehabilitation engineer and who has been working in our laboratory for 5 years and is principally responsible for much of the clinical evaluation and development of this technique.

If I might move over here, I can just show you briefly—the stimulator is not on now. The purpose of this is not to enable normal function to come back. The function is there only when the electrical stimulus is applied. So now the stimulation is off. You can see that Jim's hand is relatively flaccid, soft. He has no voluntary control. The activities that he will be demonstrating here he cannot do without some sort of active excitation of these muscles.

The type of thing we are trying to do is make it possible for a person to perform those kinds of activities that I suspect most of us here in this room take for granted as normal, daily functions—writing, grooming, eating, et cetera. So if you would like to go ahead, Jim, and explain.

Mr. EDGAR. Would you like for the rest of us to come closer?

Mr. PECKHAM. That would be fine, yes.

Mr. JATICH. First I would like to briefly show you how the system works. What I do is, I first touch this switch that is mounted on my chest and that activates the system. You will see that my hand will open. By moving my shoulder forward, my hand will close; by moving my shoulder backward, my hand will open. To shut the system off, you just hit the switch again.

Now I will demonstrate a few things that I can do with this system. First I will pick up a cup and get a drink of water.

Next I will pick up some small objects and place them in a cup.

Now I would like to demonstrate writing. What's hard about this is, I used to be right-handed, and now I have to learn to write left-handed all over again. That's the hard part. But with a little bit of practice, it may become a bit more legible and faster.

Mr. EDGAR. Do you have any sensation with the equipment at all?

Mr. JATICH. I can feel pressure on the pen through my hand, and a little bit of tingling through my arm and my hand, but that's about it.

Mr. PECKHAM. Many persons with Jim's level of injury have a slight amount of sensation. Any amount of sensation that the person has, which is residual sensation, certainly assists him in performing these functions. It is recognized quite universally in applications for orthotic/prosthetic uses that had we the ability to provide the person not only the control of the motion but also the ability to provide him with useful sensation, that his functional performance could be enhanced.

Mr. BILIRAKIS. Doctor, is medical research working on repairing the spinal cord, repairing it or replacing it?

Mr. PECKHAM. Yes, there is a significant amount of effort which is going on in the area of regeneration. I think that is generally perceived as long-term research, where if we can meet that goal, it is certainly the most desirable. This is felt to be an intermediate or a closer-term solution to enable people to regain function.

I would mention that although the applications here are being demonstrated with people who have spinal cord injury, many of the techniques that we are developing are also applicable to many other central nervous system kinds of disabilities, such as stroke, cerebral palsy, and various others as well. So the technology and the techniques are quite similar in their application.

Mr. BILIRAKIS. Why is it Jim has to use his left hand when he is, in fact, right-handed?

Mr. PECKHAM. At this stage we work with just one hand of the person, and we try to work with the person's stronger hand and the one where they have the most sensation.

Mr. BILIRAKIS. I see. In other words, even though his stronger hand normally was the right hand, he has more sensation in the left hand so it is now the stronger one?

Mr. PECKHAM. That's correct.

Mr. JATICH. I also have a little bit more strength in the left hand. I can raise my wrist, whereas for my right hand, that's it.

Mr. BILIRAKIS. Do you hold out hope, Jim, that the spinal cord replacement and whatnot is something that is going to come and possibly might be of help to you?

Mr. JATICH. Oh, yes. I always have hope.

Mr. PECKHAM. I would like to make one point, that I think these sort of applications demonstrate the importance of not only the sophisticated technology but also the knowledge and contributions that basic sciences can make to these applications. Fifteen years ago, when the original applications of this technology were attempted, the knowledge base of how the muscle operated, its basic physiological performance, was not available to us. As a result, much of the early work in this field did not succeed. It was only by the simultaneous development of the technology with this knowledge in the basic science, understanding the energetics of muscle, how muscle received its normal voluntary contraction, that we were able to in somewhat relatively crude ways apply this technology to the physiology to develop systems that could be beneficial to individuals such as Jim.

Mr. EDGAR. Jim, thank you for taking the time today to show us that.

Mr. JATICH. I'm glad you invited me.

Mr. EDGAR. The last thing we did, the handshake, it was very interesting to feel the difference between what essentially was a limp hand and what was a relatively strong hand. I appreciate that demonstration.

While I like to try and use the equipment, I was unwilling to have one of these things installed just for the day. But I do appreciate all of the panelists coming and helping to demonstrate, both the veterans and the staff.

[The statement of P. Hunter Peckham appears at p. 236.]

Mr. EDGAR. Dr. Boren.

Dr. BOREN. Next, Mr. Chairman, will be Dr. Byron Marsolais. Again, this is functional electrical stimulation, but this time it is of the lower extremities. Dr. Marsolais.

**STATEMENT OF E. BYRON MARSOLAIS, M.D., PH.D., CHIEF OF REHABILITATION MEDICINE, VAMC, CLEVELAND, OH, ACCOMPANIED BY BASAM KHAWAM**

Dr. MARSOLAIS. Thank you.

Mr. Chairman and members of the committee, I also have a prepared statement which I would like to have entered into the record.

I have worked at the Veterans' Administration Medical Center in Cleveland for the past 13 years and I am Chief of Rehabilitation Medicine at that Center. I am an orthopedic surgeon and I have a Ph.D. in engineering mechanics. In fact, modern medicine is so complicated that maximal progress can only be achieved at this time through careful integration of many fields, especially engineering and medicine.

I lead a team of 20 researchers of various disciplines who have begun to make major strides toward a safe, reliable, and adaptable system for functional walking using electrical stimulation.

Consider the situation of the paraplegic person. He has no ability to move his legs and no sensation in them. He can move around only in a wheelchair, and you have seen some examples of that. He cannot stand up, even for a few minutes. He cannot use most rest-

rooms, especially those in private homes, he cannot board an airplane without being carried on it. A single step can become an insurmountable barrier restricting or preventing his attending an activity.

There are approximately 400,000 people with spinal cord injury in the United States today, and each year this increases by about 10,000. Besides spinal cord injury, there are a number of other walking problems that this technique can help. There are 2.5 million afflicted with stroke, 2.5 million with head injury, approximately 750,000 with cerebral palsy, about 500,000 with multiple sclerosis. It is my opinion that approximately 20 percent of these individuals can be helped with this kind of technology.

We have begun to help selected patients who serve as our subjects in the research studies at the Cleveland Veterans Administration Medical Center under the sponsorship of the VA Rehab R&D. The advances we have made have demonstrated the enormous potential of this new technology and, in fact, have already begun to affect the way that medicine is practiced. Some of you probably realize that in the past most people who were paralyzed, who suffered a fracture or dislocation, were pretty much left alone. The fractures were minimally treated because it was medically certain that they would never walk again. Today's best medical care has a new attitude, based on the expectation that one day the paralyzed patient may well walk.

I have worked for approximately 13 years with functional electrical stimulation in the human, and currently I am working with a group of eight complete paraplegic patients. Their injuries range from paralysis below the breast down to about the level of the navel.

I would like to introduce to you Basam Khawam. Sam just did something that all paralyzed people would hope to do. He stood up on his own, or on his own with the use of functional electrical stimulation. Sam has absolutely no function below his ribs. He is totally paralyzed and totally asensory. He is 25 years old, an industrial engineer, and he suffered spinal cord injury due to a gunshot wound back in March 1982. He joined us in August 1982.

Notice the electrodes in his thighs. If you look carefully you can see them, and I'm sure he won't mind you coming and looking at them more closely, if you wish. We have implanted 22 in the muscles of his hips, his knees, and his ankles. Notice he has absolutely no braces on. Notice also his muscular development. He puts even my own legs to shame with his muscle development.

The computer allows Sam to control each function—standing, right step, left step, and sitting. At present he is learning to climb steps in the laboratory, but we do not have that in a portable system. Eventually these electrodes, which go through the skin, will be replaced with a totally implanted system.

Currently the computer is set up in advance with certain levels of stimulation, so that the muscles will move as we wish them to. The thrust of our current work is to develop automated controls that will enable the computer to intelligently adjust the changes to those in the environment.

This system will make an enormous difference in the quality of life, both physical and psychological. The technology we are devel-

oping will give the paraplegic person the ability to get into an inaccessible area, through a narrow doorway, to use a commode, to have an active sex life, to stand up to address a group such as this, to go up that one step which is so often the barrier preventing participation like an able-bodied human being.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions that you or members of the committee may have.

[The statement of Dr. E. Byron Marsolais appears at p. 237.]

Dr. MARSOLAIS. These electrodes are all within his muscles. There are 22 muscles within his body that have been implanted with essentially an artificial nerve which is controlled by the computer instead of his brain. So the individual muscles are turned on in proper sequence to give a very normal appearing walk. It is not possible to do this without implanting. That is where we have to have the real marriage of medicine and engineering. We have a combination of surgery and the highest engineering technology that there is in order to achieve this kind of a possibility.

Some of you may have seen some of this on television a while back in a national television program. That was not our work, but that was work similar to work we did many years ago with stimulation through the skin. We found we were not able to do that successfully to get the complexity we needed, and that implants are essential to try to duplicate natural walking.

Mr. EDGAR. Thank you very much for demonstrating that for us.

I would like to thank our physicians and our patients who have demonstrated and shared themselves with us this morning.

Dr. Boren.

Dr. BOREN. I would like to continue now with Dr. John A. Trimble from the Hines VA Medical Center, demonstrating the talking braille teacher.

**STATEMENT OF JOHN L. TRIMBLE, ACTING DIRECTOR, REHABILITATION RESEARCH AND DEVELOPMENT CENTER, VA HOSPITAL, HINES, IL**

Dr. TRIMBLE. Mr. Chairman, I have a prepared testimony that I would like to submit for the record.

Mr. EDGAR. Without objection, your full statement will be made a part of the record.

Dr. TRIMBLE. Thank you.

I am pleased to have the opportunity today to discuss the work that we are doing at the Rehabilitation R&D Center of Hines Veterans' Hospital on reading aids for people who are visually impaired.

The inability to read has been called the most frustrating, limiting handicapping aspect of blindness. It is a significant problem for literally thousands of veterans. Our goal at this center is to help these people to read, to allow them more access to printed material. Our approach to solving the problems of visually impaired veterans essentially involves four steps. The first step is to understand what they need and what their abilities are. For this step we use a rather unique approach, and that approach is that we ask them sometimes formally in terms of surveys, and we also ask them in-

formally in terms of consultation with rehabilitation professionals and disabled consumers. Once we have determined what their needs and abilities are, we then look around to see whether or not there is any existing technology that we can directly apply to solving their problem. If there is not, we then develop our own technology. If it is apparent that there is no technology that can solve their problem, we then must do research to develop that new technology.

When we examined the needs of visually impaired veterans, we found two groups of people that have dramatically different needs and abilities. By far the largest group of people are those who are partially sighted. Even though they are termed legally blind, they, in fact, have some residual vision and most of them can read ordinary print with special aids.

The problem in this case is not that the aids are inadequate. There are plenty of aids and most of them work pretty well, although some of them could stand a little improvement. The problem in this case is really one where it is very, very difficult for the clinician to match a particular reading aid to a particular individual's capabilities. It is one of actually prescribing the right aid for a person, given that person's capabilities.

In order to solve this problem, we needed to know more about what partially sighted people see and how they look at the world. We believe that if we understand how partially sighted people view the world then we can perhaps better apply our technology to help prescribe the appropriate aid for them.

We are learning this by using techniques similar to those used in the space program for processing images from satellites and other devices to distort pictures so they appear like they do to people who are partially sighted. My colleague, Dr. Robinson, will now show you two pictures. The picture on the left has been processed by a computer, and it has been processed in a way so that it represents basically what you as a normal sighted person will see. The picture on the right has been processed with the function which basically describes how somebody with 20–200 vision—in other words, somebody who is legally blind—sees the world. When these pictures are viewed from a distance of approximately 20 feet, the person who has 20–200 vision cannot, in fact, tell the difference between the two pictures. The two pictures look absolutely identical for that person.

What we are doing now is we are analyzing what it is about the picture on the right that makes it very difficult for people to actually use that picture in order to gain information—for example, in trying to determine who it is he's looking at, in recognizing faces. We are also using similar techniques to attempt to determine what it is that makes particular letters easy to identify or hard to identify, in order perhaps to develop print that may be more readible to people who are partially sighted.

The other group we found when we were looking at the needs and abilities of partially sighted people were people who were blind, totally blind. Even though these people both in the Veterans' Administration and nationally are in the minority, their needs are considerable and significant. They, in fact, need a variety of aids to deal with all of the different reading materials that they encounter

in daily life. Earlier this morning we heard mention of some of the new computerized aids that are available, some of the reading machines that read pages and speak the words on the page. These are certainly incredible advances and they are helping these people tremendously. But still, they are not allowing them the independence they need to read whatever they want, whenever they want, by themselves.

We approached this problem by trying to work on an aid which we believe gives nonsighted people the greatest independence possible with the present technology. That aid is 150 years old and it's braille. Braille is a very useful language for people who are visually impaired. As a matter of fact, some people have said that braille is to blind people what pencils are to sighted people. It is convenient for taking notes. It still the only way you can figure out what floor you're on in an elevator, and it is also a very convenient way for labeling your groceries when you bring them home from the grocery stores so that you can find them in your cupboard again.

When we looked at the problems with braille, we found that basically there were two of them that were significant. The first problem is that braille is very difficult to learn. It is like learning a foreign language, except you also have to learn how to read with your finger, which makes it doubly hard. The second problem with braille is that it's very expensive to produce, and also time-consuming.

In order to solve the first problem, the learning problem, we looked to the consumer technology industry. In particular, we found a new child's toy that we believe will make it very easy for people to learn braille, and with the help again of my colleague, Dr. Robinson, I will show you that now. As a matter of fact, I would like to pass this up to you so you can——

Mr. EDGAR. We already have it.

Dr. TRIMBLE. Oh, you have one already. Good.

The instrument is called the "Magic Wand Speaking Reader", developed by Texas Instruments. It works basically like the bar code readers that you see in many grocery stores nowadays.

There are special books that go along with the reader which we have simply added braille to, so that in order to learn the braille that is printed on the page, all you do is feel the braille and then pass the wand over the bar code. The wand will say whatever the braille says.

Also in these books we have used a special paper. You will notice that all of the pages in these books have raised symbols. These pages were actually xeroxed on an ordinary xeroxing machine. It is a special paper recently developed by the Japanese which uses microcapsules.

With these books, which we are now evaluating, we believe that people will find it much easier to use braille. It will also make braille learning systems much more accessible to people. The current price of this device is $29.97. We are working with Texas Instruments to produce special braille books for the Magic Wand Speaking Reader and we believe they will sell for very little more than the standard book for sighted people, which is $12. So, in short, we have used existing technology to solve a very big problem that people have in learning braille.

Our new books also will be printed, rather than using the xerox paper, with a special ink that allows raised symbols to be printed just as ordinary ink symbols are printed. If I may pass this down, this is a sample of print. From the writing on the paper you will notice that this is also Japanese, but there is a chemical corporation in the United States that we are working with which will formulate that ink for us if they can be convinced that the market for it is great enough. This will allow any raised material to be printed in an ordinary printing press.

That concludes my testimony and I will be happy to answer any questions you or any members of the committee may have.

[The statement of John L. Trimble appears at p. 28.]

Mr. EDGAR. On the Texas Instruments item here, this device goes across like you would do at a supermarket, across this?

Dr. TRIMBLE. You just hold it vertically and scan the pointed end right across the bar code. We have added raised lines above and below the bar code, as well as we have raised the star that is to the left of the bar code, so that people who are nonsighted can easily find the bar code on the page.

I have to emphasize that the books you have are direct copies of the kids' books and it is certainly not going to be our final product. We are working on developing books specifically for visually impaired adults. Texas Instruments is helping us in that respect.

Mr. EDGAR. Thank you. I have no additional questions and appreciate what you're doing and look forward to keeping an eye on it.

Dr. TRIMBLE. Thank you very much.

Mr. EDGAR. Dr. Boren.

Dr. BOREN. Next we have Mr. Woodrow Seamone of the Johns Hopkins Applied Physics Laboratory to demonstrate a robotic arm and worktable. Mr. Seamone.

## STATEMENT OF WOODROW SEAMONE, PROJECT MANAGER, PROSTHETICS-ORTHOTICS RESEARCH PROGRAM, THE JOHNS HOPKINS APPLIED PHYSICS LABORATORY, ACCOMPANIED BY DR. GERHARD SCHMEISSER

Mr. SEAMONE. Mr. Chairman and members of the committee, I, too, have a prepared statement which I would like to enter for the record.

Mr. EDGAR. Without objection, it will be made a part of the record.

Mr. SEAMONE. My name is Woodrow Seamone. I am with the Johns Hopkins University and I am the project manager on the application of robotics to the needs of the high spinal cord injured person. This program is jointly shared with Dr. Gerhard Schmeisser, here on my right, who is a professor at Johns Hopkins School of Medicine and also associate director of the Department of Orthopedics at the Johns Hopkins Hospital.

The subject of my testimony is a robotic arm/worktable system which has been under development since about 1974. This work has been sponsored by the Rehab R&D Service. The objective of this development is to provide a single mechanical device which provides many kinds of capabilities for the high spinal cord injured person. One important objective is to maintain the capability of the wheel-

chair mobility as part of this total system; another important objective is to maintain the cost at an affordable level. Our target cost for the total system is under $10,000.

The entire system is central around a computer controlled arm. Whereas the previous robot arm that was demonstrated earlier has all the electronics and computers contained in a cabinet, containing many microprocessors, we use a single microprocessor on a board. This electronic board contains the total controls for the system. It is vertically mounted in the arm. This is a key element which could lead to a low cost system.

Positioned on the worktable within reach of the arm are various devices which allows one to do useful tasks. We have an electronic typewriter, a reading stand, a telephone system, and we have the capability for self-feeding. All of these tasks can be accomplished with very little attendant assistance, and in some cases none at all.

I would like to introduce John Loveless of the Johns Hopkins laboratory who is in the wheelchair. He will first demonstrate how the wheelchair is operated, and then he will drive up to the worktable and use an electro-optical link, which is between the wheelchair and the worktable. He can transfer the control with his chin from the wheelchair motors to the robot arm on the worktable. We do that with an infrared link which is contained on the right side of the wheelchair.

John is now turning off the wheelchair motors and then turns on the command system to the robot arm. This system takes advantage of many stored programs to manipulate equipment on the worktable. John is calling up a program to move the mouthstick into position. This is a stick which quadriplegics quite often use in their mouths. It is used for turning pages, for operating a typewriter, for dialing on a telephone, and it only costs about $2. It is a very important adjunct for the high spinal cord injured person to provide some manipulation capability.

This computer may be programmed to carry out desired tasks, and it does not have to be necessarily programmed by the engineers who designed it. I have with me a programmable keyboard which allows programming very similar to keyboards used in basic language on personal computers. We have trained therapists and users on how to program use this keyboard. It is very simple to use. You can program the arm to do whatever you would like it to do.

John is controlling the robot arm with his chin control and is now calling up various stored programs. He can stop the arm at any time and cause it to stopmotion in any of the 6 degrees of freedom of the arm. Presently he is in a stored program mode which he has called up, and any time he chooses to stop, he can readily stop this motion.

We found that the programming concept allows one to use a lot of repetitive operations which reduces effort on the part of the user and yet gets the job done. I believe John is now calling up the phone. The telephone hearing piece is on the right side and we have the microphone part of the telephone down in the bottom of the mouthstick.

This system has been used in actual clinical testing and the users find it very useful because they like to use a private phone like nonhandicapped persons. They do not want a speaker phone,

which is also very easy to use and very easy to turn on, but instead would like to carry on a normal conversational mode.

While John is using the telephone, I would like to just tell you about a veteran quadriplegic volunteer who has worked with us at the Richmond VA Center. It was 6 years since his injury and communication by way of written word was something he never did after his injury, because how could he communicate if he couldn't use his arms?

After 2 months as part of the VA evaluation program in Richmond, Mac learned how to use our system. He used a slightly different work table arrangement than the sample table here today. We have a personal computer on our systems out in the field. Mac was able to input the computer without a keyboard. He used the Morse Code input system, using his chin. With this system he not only learned how to do Morse Code; he also learned how to operate a word processor program. Following this, he very quickly wrote two articles, he submitted them for publication, and they were subsequently published. He revised and typed his own résumé because he now feels he can actually get a job. He formatted a technical abstract for a doctor, and then he wrote a 300-word letter for a friend. This individual spent 2 to 5 hours a day at this machine. He could drive up, use the robot arm system, and he could drive away at his own discretion.

When he completed our program, after 2 months of evaluation, he said "I not only want the arm, but I also want a personal computer."

John, would you drive over to the self-feeding side, please.

In order to feed a person, we must consider wheelchair management. We allow the wheelchair to leave the area where it is docked and John will drive around to the other side and redock on the table side on the right.

Without any attendant assistance, John can leave this area and drive to the other side. Of course, when you are going to feed yourself a meal, you do need some help in having the food brought to you, and you also need some help in placing this utensil on the robot arm. Dr. Schmeisser is going to illustrate by placing the utensil into position when John is in the eating position and then command the arm to allow the utensil to be placed in place.

On the right side of the table are two plates and a bowl. These are not fastened. They are ordinary plates. We have tested various kinds of food. In other words, we have evaluated eating foods like meat, potatoes, salads, fruit cocktail, and almost anything you can imagine. This is the point in the cycle where the attendant would have brought the food, placed it in the plates, and placed the utensil into position. John will then command the system, by the chin control, to either select food in any of the plates or bowls and select any particular portion of the food.

Being in total control of the self-feeding process can be a major factor in your feelings of self-esteem. Even though one needs assistance to place the spoon into its intended position, and someone must bring the food to the plate, once that is done you are on your own. You are able to sit down, have a meal, and perhaps go back to eating with your friends. You don't depend on your friends bring-

ing every bite of food to your mouth. This allows you to socialize while you eat.

That is not real food in the demonstration. It is bits of foam.

The volunteer quadriplegic that I spoke about earlier, has used this system for eating for 39 luncheon meals. His pride was to be able to eat a complete meal without leaving any trace of food in any of the bowls or plates. This typically took 30 to 40 minutes, but he did it on his own.

Gregory, who was another quadriplegic in Richmond, described his lunches with the robot as being near perfect except for the fact that we didn't get rid of the taste of hospital food. We're going to have to work on that problem.

I would like to mention the fact that we have maintained the use of the quadriplegic volunteer as an input to this system throughout our program. About 2 years ago the VA Rehab R&D set up two centers, one in Richmond, VA and one in Cleveland, OH, as centers to test the system. We furnished these centers a wheelchair, the controller, and we put that under the total control of the individuals at that center, typically a therapist. We have had 12 volunteers participating in this program for the period over the last year-and-a-half. Some of these evaluations take 2 months at the rate of 20 hours a week. As of the beginning of the year, the overall consensus was that this was a very useful system for these quadriplegics since it gave them independence for certain kinds of activities which they were very interested in.

They did have some complaints. For example, they wanted to be able to brush their teeth, groom their hair. These are tasks we all take for granted, but these are important. We are going to add these features in future models.

One quadriplegic ate 50 meals with this system. All of the users found possible system use very easy to learn and were not concerned with the safety. Since this robot is designed specifically for the quadriplegic, we do not have a high force level system and this can operate in the vicinity of the face. You don't have to worry about the spoon as it comes into your mouth.

John is now commanding the arm to drop the utensil. You can leave the dirty dishes for the attendant and drive back around to the other side and continue with your vocational tasks when eating is finished.

The VA Rehab R&D is now in the final negotiation phase with the potential manufacturer of this total system. This contract is expected to be let shortly, hopefully some time early in 1984. This contract, if it produces a successful prototype model, will lead to the manufacture of 1,000 units like this one we have demonstrated for the VA spinal cord injury centers. Johns Hopkins is planning to assist in the transition from the R&D phase, which is what you see here, to the actual prototype stage.

The relevance of this project to the VA mission is to provide an increased measure of independence to certain types of quadriplegics. It can reduce the attendant service, which can be a very high cost, and has a significant potential for improving their quality of life.

Before I conclude, I would like to share another statement that Mac, the quadriplegic volunteer, said when he described the

system. He described it in one word, "liberation." When asked if there was something else he would like the robot arm to do, he replied, "Come home with me." He really wanted this system.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions.

[The statement of Woodrow Seamone appears at p. 240.]

Mr. EDGAR. Thank you very much.

How long has this system been under development?

Mr. SEAMONE. We started the program in 1974, long before we had small computers and low-cost mechanical devices. It is only in the last 4 or 5 years that we have been able to come up with a low-cost system which really will give you this kind of capability.

Mr. EDGAR. What is your hope for a system like this in terms of its development?

Mr. SEAMONE. Do you mean the cost?

Mr. EDGAR. What is your hope for it? How widely do you think this can be used by VA patients?

Mr. SEAMONE. Well, we hope it will be applied both in the VA spinal cord injury centers and be available to those quadriplegics who are now just discovering there are other things they can do besides sitting around in their wheelchairs and simply watch television. It is a device which hopefully will allow some of these people to leave the VA centers and go home and stay there because they can do these various functions. They have something worthwhile to do with this kind of a system.

Mr. EDGAR. Very good.

Have you had any patient involvement with the system where they felt alienated by it, or has it been the other way around, that they felt humanized by it?

Mr. SEAMONE. We have had no real problems as far as alienation by this robot arm. In one case, for example, we had a quadriplegic whose wife feeds him all the time. He said he would much rather have his wife feed him than a machine. But in most cases, most quadriplegics will select the machine over an attendant in the VA hospital because the attendant does not have the time, does not socialize and does not share with you a nice conversational kind of lunch. He simply feeds you in about 5 minutes.

Mr. EDGAR. Thank you very much for your demonstration. I want to thank the other doctors and assistants that you used to show the system and how it works.

Mr. SEAMONE. Thank you very much.

Dr. BOREN. Next we have Dr. Thomas Krouskop from the VA Medical Center in Houston, who will speak on computerized fitting of prostheses.

**STATEMENT OF THOMAS A. KROUSKOP, ASSOCIATE PROFESSOR OF BIOENGINEERING, BAYLOR COLLEGE OF MEDICINE, HOUSTON, TX**

Dr. KROUSKOP. Mr. Chairman, members of the committee, I have a prepared written statement that I would like to submit for the record.

Mr. EDGAR. Without objection, your full statement will be made a part of the record.

Dr. KROUSKOP. Thank you.

Today we would like to discuss our VA-sponsored project in how to use computer-aided technology in the manufacture of artificial legs. The VA has a growing number of patients, particularly elderly veterans, who suffer from peripheral vascular disease that results in them losing a part or section of their legs and becoming candidates for an artificial leg.

With the growing number of people in this category, coupled with the relatively constant number of prosthetists who are available to fit the legs, we have an exciting opportunity to use computer technology to increase the number of units that can be made available without decreasing the quality of the product and at the same time lowering the per unit costs of the final product.

When a veteran enters the prosthetic delivery system he is seen in a prosthetic clinic at the VA medical center where the prostheses or artificial leg or arm is prescribed. He is then assigned to the prosthetist who then sees him in his shop and makes the artificial limb.

The process of making the artificial limb and providing it can be simply phased in four parts. The first part deals with making the socket. Now, this is for an above-the-knee amputee and is really a cup that holds the residual limb and serves to transfer the body weight from the body to the artificial leg. How well that leg performs and how comfortable it is depends on how well the socket is shaped to hold the stump.

The second phase of the fabrication process involves assembling all the components—the socket, the shank of the prostheses, and the foot, for instance. Then these components are fitted on the person and an alignment is made to optimize the performance for the individual. Then the fourth part of the process is the training of the individual on how to use his new device most effectively.

This first phase of the fitting process, the fabrication of the socket, is one of the more time-consuming parts. It requires a substantial amount of handwork and a considerable amount of expertise developed through experience on the part of the prosthetist. It is this part of the fitting process that we are addressing in our project.

When the prosthetist goes to make a socket, the first thing he does is to define the shape of the residual limb by making a plaster mold of it. At the time that he makes the mold, he also, by feeling the tissue in the residual limb, determines how firm it is, how much musculature is still there, how much the skins moves, how much the flesh will move around, so that when he then starts to modify the initial mold, he knows where to cut and how to shape the mold so that when the socket is made it will fit and distribute the body weight so that it doesn't pull on scarred areas causing them to try to shear and break apart, and also so that areas, particularly on the leg, that are sensitive to pressure aren't subject to pressure that would cause pain.

Now, the cast modification process is really the most time-consuming part of this endeavor. It can take anywhere from about 45 minutes up to several days, depending on how many times you have to go through the process of making a socket, putting it on the patient, testing it, and bringing it back and modifying it a little

bit more. It is this process that we are using the computer-aided design and manufacturing techniques to accomplish.

Now, like the prosthetist, there are certain pieces of information that we have to have to use to characterize the stump. The first of these is we need to know what the shape is. I would like to have my colleague, Barry Gude, help with the demonstration on this.

We have developed what we call a contourgraph—if the people would like to come down closer, they may—that traces the shape of the stump at various levels. We go around once and drop down, and go around again, so that we can define in space what the surface of that stump looks like. This is a first generation instrument that we use by hand. There is a second generation instrument that actually should be fabricated about today that is fully automated and can be easily tied to the computer directly.

If Mr. David Gorman would come up, we will attempt to show how this device is used with a person rather than with a model.

In this process the amputee would be positioned over the contourgraph and the stump would be placed in contact with the plastic insert. With practice, and when you're not demonstrating in front of a whole lot of people, the process generally takes about 8 minutes.

Once the shape of the stump has been characterized and stored in a format that the computer can understand, we then have the problem of trying to understand, in the same way that the prosthetist does, how firm the tissue is that makes up that stump. To do this, we have developed an ultrasonic device that uses the same sorts of transducers that are used to make a sonogram to look at the unborn fetus. Only in this case our device is a hand-held instrument that is placed against the skin, and by putting it at predetermined points, depending on whether the amputee is an above-knee amputee or a below-knee amputee, we can characterize the important muscles and the amount of fat and skin, the mobility of the skin that is present. Also, the transducer gives us an opportunity to visualize where in the stump the bones are relative to the surfaces.

Once this information has been collected and made available to the computer, the computer generates its own model of what we have characterized and generates a picture that basically looks like this. The section down through here represents where the femur is. This is an above-knee amputee. The soft tissue, the muscles. The femur is down through here, and the muscles and other soft tissue surround it. It makes as accurate a picture as we are willing to take the time to represent into the computer. The computer then uses this information in connection with a relatively new analytical technique to determine what the shape of the stump should look like, so that the body's weight is distributed evenly over the surface, and also spots that are sensitive to pressure or sensitive to abrasion-type loads are accounted for.

The computer then generates what this shape should look like. Again, the bone, the femur, is along this section. The dotted lines represent the original shape. The solid lines on this represent the deformed shape, which comes in. The information from that analysis is then used as an input to another machine that is computer

controlled and it can be used as a router or as a milling machine to form a piece of foam to the shape of the socket.

This form is then used in the conventional ways that the prosthetists make the socket, in that plastic is laminated over that surface and the form is pulled out, leaving the socket like this. I will pass this around for people who would like to see it.

We are excited about this project because it does represent an opportunity to decrease the amount of time that is required to fabricate a prosthesis, and thus decreases the delivery time required to serve the veteran population. Instead of taking on the order of hours to determine what the deformed shape is, once the data is collected on the shape and the engineering properties of the tissue, the computer takes anywhere from 4 to 8 minutes to generate what the deformed shape should look like. So the entire socket can be done in less than an hour rather than on the order of a day.

It also represents an opportunity to not require the amputee to spend considerable time in the prosthetist's office being fitted and going through the irritative process of being fitted. We should be able to use regional centers to fabricate the sockets rather than having to have it done on an individual remote basis as it currently is.

This concludes my remarks and thank you, Mr. Chairman. I would be glad to answer any questions.

[The statement of Thomas A. Krouskop appears at p. 241.]

Mr. EDGAR. Thank you very much for the demonstration and for your very competent testimony on this particular issue.

I just have one question in terms of where the stump fits into the prosthetic device, the knee. Can you describe a little bit the problems that you face in terms of that adaptation? Are all veterans able to handle that, or do some have more sensitivity than others in terms of the issue of pain?

Dr. KROUSKOP. Pain and comfort are individual things. We all have different thresholds on what is comfortable and what is uncomfortable. The amputee has the same set of problems.

The big problem is, whenever you start to try to put a piece of flesh down into something that is relatively stiff, you can't compress soft tissue. You can deform it, but you can't compress it. It is mostly water and it won't compress. So it has to move somewhere. When you start trying to cram things down into something that doesn't give, something has to move somewhere else. That process of moving around is what causes people to have pain and discomfort.

Also, if the tissue doesn't fit down into this cup properly, the cup will tend to move relative to the tissue and cause blisters and other forms of discomfort.

Mr. EDGAR. Are there new materials being developed that will ease that problem?

Dr. KROUSKOP. Yes, there are. There are a number of different materials that are actually currently being used that work a whole lot better. Mr. Gorman had a liner in a hard socket that is soft and it helps ease some of that problem.

Mr. EDGAR. Thank you. I have no further questions and I appreciate your testimony.

Dr. Boren?

Dr. BOREN. Next is the Seattle Foot that we have heard so much about. Dr. Margaret Giannini from central office will speak on that.

**STATEMENT OF MARGARET J. GIANNINI, DIRECTOR, REHABILITATION RESEARCH AND DEVELOPMENT SERVICE, VETERANS' ADMINISTRATION, ACCOMPANIED BY JAMES MAYER, STAFF ADMINISTRATOR, PARALYZED VETERANS OF AMERICA, INC.**

Dr. GIANNINI. Mr. Chairman and members of the committee: My name is Margaret Joan Giannini, M.D. I am the Director of the Rehabilitation Research and Development Service and I am responsible for the research that you have seen thus far today, and I hope that you will continue to see that remains on the program.

I was appointed to this position on April 13, 1981. For 36 years as a clinician, researcher, professor, and administrator, I have devoted my professional life to serving handicapped persons, both nationally and internationally. I was privileged to have been appointed by President Carter as the first Director of the National Institute on Handicapped Research and I am currently a member of the Institute of Medicine of the National Academy of Science.

Even though this is not my personal research, I am delighted to substitute for Dr. Burgess and have the opportunity this morning to present to you the VA's—I repeat that—the VA's Seattle Foot. It is an exciting new prosthetic foot developed in our VA Rehabilitation Research and Development Program headed by Dr. Ernest M. Burgess, who is the principal investigator at the Research Center in Seattle, WA.

The newly developed VA Seattle Foot is a high performance foot designed to store the energy of weight bearing and to release this energy at the time of tip off of the toe, roughly simulating the action of a normal leg, of the gastrocnemius muscle or the calf muscle of a normal person. It does this by means of an internal "keel", this black thing that you see—and I'll pass it around—or spring member that is designed to deflect underbody load. The keel is made of high-strength plastic, which was designed for us by duPont, called delrin, and the remainder is scientifically designed to store energy as efficiently as possible. The soft polyurethane foam is one of the usual foams that is used in many other kinds of devices. This foot, however, is designed in such a way that this foam has high durability.

The VA Seattle Foot shows great promise for enhancing the qualify of life for veterans with limb loss. And for just a moment, the mission of Rehab R&D is a very simple one—to improve the quality of life of disabled, infirmed, and handicapped veterans.

The use of this foot will not only be cost effective, but it will also provide many physical and psychological benefits, including the opportunity to improve physical fitness among this large group of young, severely-disabled veterans. Studies have indicated that there is a greater frequency of heart disease among amputees in the VA population. This is no doubt attributable to their, in many cases, sedentary lifestyle because they are unable to have many opportunities for physical exertion by way of recreational sports. We anticipate that the VA Seattle Foot, by facilitating increased physi-

cal activity, could impact positively on the expected longevity of lower limb amputees.

Research to develop the entire family of improved prostheses, the artificial limbs, for lower limb amputees began at Seattle, Washington in 1979. Presently we have 38 such feet that are being subjectively and scientifically evaluated, subjectively evaluated among many of our VAMCs throughout the country, and scientifically being evaluated at our own evaluation center here at the Washington VAMC.

We are analyzing certain things: What is the fatigue-ability of the foot, what is the comfort of the foot, does the wearer and the user like it, does it give him more agility, does it allow him better mobility? We are also studying gait analysis to see what the force plates are and many other parameters which I won't burden you with, so that we will know whether the life cycle of this foot will be 50,000 steps, 20,000 steps, 100,000 steps or whatever. We are working this out with the Army laboratory in Natick, which has one of the best step apparatuses in the country.

Much of related research in the last few years has concentrated on high technology, particularly in the use of externally powered devices and complex hydraulic and other systems. The point that I would like to make here is that when this was pursued—These are very simple materials, quite different from the former materials that were used, such as in the S.A.C.H. foot, which is also a product of VA research, but is a little different, much more durable and more for the elderly rather than the young, who are very rugged and active in their activities of daily living.

We are presently producing 500 such feet, so that in parallel we can distribute them around the country for further evaluation and to further develop a more perfect Seattle Foot.

I think it is a major contribution because it allows our young disabled veterans, especially the Vietnam veterans, who have amputations of either a single nature or a double, to become a member of recreational activities that he was not able to do formerly.

Mr. Chairman, this concludes my formal statement. I would be pleased to answer any questions.

[The statement of Dr. Margaret J. Giannini appears at p. 242.]

Dr. GIANNINI. Now, Mr. Chairman, I would like to present Mr. James Mayer of Silver Spring, MD, who is staff administrator for the Paralyzed Veterans of America. Mr. Mayer is wearing two VA Seattle Feet and he will demonstrate their use by walking, as you have seen Dave Gorman do as well. But Jim is going to be jogging with you, I think, in a little while, isn't he?

Mr. EDGAR. We are going to have a race. [Laughter.]

We're going to jog from the Horseshoe to the Capitol steps between noon and 12:15. I would hope that some people might come out and have an opportunity to see the stability of those feet.

Jim, do you want to say anything about it?

Mr. MAYER. Just before I try something here, it is a little difficult for me to do this on carpet, but I'm going to try and jog just a bit and do a little bit of a jump. Again, this is on carpet, and I'm wearing loafers.

[Demonstrating.] [Applause.]

Mr. EDGAR. Very good.

Part of this process of making this foot work is a new space-age plastic that you identified as delrin, which is used in the base of the foot. I am advised by my staff that the material has been used to replace another ancient form of technology and that is, namely, in the harpsicord striking mechanism. I have one of those striking mechanisms here, which is made out of the same material. This used to be made out of boxwood and raven's quills during the 18th century and used within the harpsicord, and now, because of the advance of this kind of technology, you can have the same sounds that a harpsicord has melodiously given for a long time more modernly with this material.

The new plastic is more durable and reliable to do that kind of delicate work in hitting the strings, but there is some question as to how long it will last, and you mentioned the studies you're doing on this.

What experience have you found, in terms of your early preliminary studies, on the durability of this kind of plastic material within that foot?

Dr. GIANNINI. Well, the delrin is excellent. We don't seem to have any problems with that. We are having problems with the foam because there is a kind of shearing action that takes place after extensive wear. I think that Jim can attest to that. He has had a few feet so far.

Mr. EDGAR. Of the 39 feet, he's had a few of them.

Dr. GIANNINI. I think he has about two, haven't you?

Mr. MAYER. This is the third set.

Dr. GIANNINI. But he is very rugged with his feet. He jogs quite consistently and gives it really hard wear. So we are very pleased with that activity and it gives us a lot of information. But the shearing is a problem which we will resolve. I have no doubts of that. I think that we will have to probably have some creative ideas on how that polyurethane is going to be layered, the foam, but I think the delrin will remain to be perfect.

Mr. EDGAR. And you don't think this will become brittle at some time in the future?

Dr. GIANNINI. Well, I don't want to be that positive, but I think thus far we have had no problems with the delrin at all.

Mr. EDGAR. Jim, I wonder if you might make a comment or two about the three sets of feet that you have had and then make some comments about them compared to other feet which have been utilized.

Mr. MAYER. Well, speaking as an individual, I have been using Seattle feet since last October 1983. The set that I am wearing today I have had for almost 4 months and I have had no problem whatsoever. I never had a problem with the delrin, or the spring, the keel, at all. As Dr. Giannini mentioned, there was a slight problem with the foam, the normal foam that forms the foot. And since I was so active and the first bilateral to wear Seattle feet, I have a tendency, as most bilaterals do, to hit on my heel on my step. I helped cause a little bit of breakdown with that. But for 4 months now I have had no problems whatsoever.

I jog, I play racquetball, and this summer I am looking forward to playing softball, because during other summers in the past I

have been a member of a team that gives me a "designated runner" and this year I want to try it on my own.

Mr. EDGAR. That sounds great.

What is the cost of a pair of feet?

Dr. GIANNINI. We have a costing out so far of somewhere between $50 and $60, which is less than any of our other feet, such as the S.A.C.H. foot or the S.A.F.E. foot.

Mr. EDGAR. And you would anticipate that you could wear these for what, 6 months, a year, 2 years, before replacement?

Dr. GIANNINI. Well, it depends on the amount of rugged activity. For instances, what Jim just commented on, for 4 months now with his very active activity, that is rather good, because we haven't done anything different to the foam which collapsed on him in two other sets, so that says something for the foot in terms of its stability.

However, I think what our projections will be is that hopefully they would last a year, at least a year. That is usually what the other feet last.

Mr. EDGAR. What about the Office of Management and Budget giving the VA adequate funding for the production of these feet? Has there been any problem at all?

Dr. BOREN. No, there has not been.

Mr. EDGAR. And what do you anticipate would be the production stage of these once the testing is completed?

Dr. GIANNINI. Well, the number of amputees that we have were cited, and we don't have that broken down into single and double amputees. But whatever that number is, we can plan on having at least that on an annual basis.

Now, that is a little bit incorrect because with our geriatric population, even though this is not designed for the geriatric amputee specifically because they don't need this lightweight, very rugged kind of foot, but they may be an active kind of individual, so I am sure that we will be supplying them for certain numbers of geriatric amputees as well. And those are increasing annually on a very large scale.

Mr. EDGAR. Thank you very much. I have no additional questions. Jim, do you have any additonal comments?

Mr. MAYER. Yes, and that is just to try and describe what Dave Gorman mentioned before, the feeling of using a Seattle foot, other than the gain in activities that I can do, to run, to play sports much more effectively and competitively, just the physical feeling. It is as if my calf muscles are attached again or are actually lifting my foot at the end of the transfer step. I haven't felt that since April 24, 1969, the day before I was injured.

And to pick up on what Dr. Giannini was saying about my own personal rugged use of the Seattle foot: I am not a scientist, I'm simply a disabled veteran and a user. But I am absolutely convinced that the Seattle foot is ready to go to the marketplace as soon as possible, I really do.

I thank the VA, I thank most of all Dr. Ernie Burgess, and I thank you, Mr. Chairman, for these hearings.

Mr. EDGAR. Thank you. I appreciate that and appreciate your statement.

Dr. Boren.

Dr. BOREN. Our last indoor demonstrator is Dr. Dudley S. Childress from the Chicago Lakeside VA Medical Center. Dr. Childress is going to present the myoelectric upper limb prostheses.

**STATEMENT OF DUDLEY S. CHILDRESS, DIRECTOR, PROSTHETICS RESEARCH, VA LAKESIDE MEDICAL CENTER, CHICAGO, IL, ACCOMPANIED BY WILLIAM DELLENBACK AND THOMAS RUTKOWSKI**

Dr. CHILDRESS. Thank you, Mr. Chairman. I also have a prepared statement which I would like to enter into the record.

Mr. EDGAR. Without objection, your full statement will be made a part of the record.

Dr. CHILDRESS. I am pleased to be the anchor man, or I thought I was the anchor man, but I understand now that you and Jim are going to be the anchor men for this relay.

Not only am I associated with the VA Lakeside Medical Center and Northwestern University, but I happen just at this time to be the president of the Rehabilitation Engineering Society of North America. I want to say that I am proud of what I have seen here today of the use of technology in rehabilitation. I am also proud to be a citizen of a country that uses some of its resources to bring technology to the aid of disabled people.

I would like to briefly talk to you—and I'm going to try to make this a fast anchor, I know you need to get out.

Mr. EDGAR. We need to be on the run.

Dr. CHILDRESS. I want to talk to you briefly about hands because they are a little different than feet. When a person loses an arm or a hand, not only do they lose function but they also lose appearance, both static and dynamic, and there is also something about them as far as their personality is concerned. The hands, like the eyes, are sort of an insight into a person's personality. In fact, the portrait photographer Karsh has said that the hands tell him something about a man because they are representative of the person.

Our hands are very tremendous tools. We don't really recognize that in some cases because they are so perfectly formed and they do our bidding so correctly and so effortlessly that we don't think about it. Aristotle said that "the hand is the instrument of instruments," and Harris, a writer in the Chicago papers, said that "computers may soon replace many men who work with their minds, but nothing can replace that finest tool of all, the human hand."

One of the aspects of the human hand is its subconscious control and we use it without thinking about it. One of our objectives in prosthetics is to try to give subconscious control to the individual. One of the ways to try to do that is to use the residual neuromuscular system that remains after amputation, such as the muscles that remain in the limb, and to use the myoelectric signal that comes from these muscles to operate hand prostheses.

Rather than go into detail about this, I would like for some gentlemen who have come with me to demonstrate this to you. This is, as you know, the 100th anniversary of former President Truman's birth. I grew up about 25 miles from Independence, MO, so I know what it is to be from the "Show Me State." I think, after being in

these hearings this morning, although I know you're from Pennsylvania, you must have a little "Show Me State" in you because of all these demonstrations.

So what I would like to do now is ask two people who have come with me, both of whom happen to be from Indiana, to demonstrate myoelectric prostheses. Not only do these people use myoelectric prostheses in their daily lives, but they also contribute to our research. I think you have seen in the testimony this morning that disabled people contribute very much to the research and push it forward and help it and we are very much dependent upon their input.

With your permission, I would like to introduce Mr. William Dellenback, who is a photographer at Indiana University and associated with the Kinsey Institute. He is a below-elbow amputee.

I would also like to introduce to you Mr. Thomas Rutkowski, who is a lawyer with Bethlehem Steel Corp. He is a senior supervisor for personnel services there, responsible for safety and workmen's comp, insurance, EEO, and their medical facility. I would like for them to come forward and demonstrate their prostheses and to interact with you and I will try to keep out of the conversation.

[The statement of Dudley S. Childress appears at p. 244.]

Dr. CHILDRESS. Bill, would you and Tom like to go to the table. I will let Bill go first.

Mr. EDGAR. Do you want us to come down closer to see it?

Mr. DELLENBACK. I don't think it's necessary. You can judge as we go along.

## STATEMENT OF WILLIAM DELLENBACK

Mr. DELLENBACK. I lost my hand about 12 years ago, or more than that, and I have been with Northwestern since that time. I don't want this to sound like a Hollywood awards dinner, but I am certainly pleased that I was able to get in with the group and I am thankful to Dr. Childress and his colleagues and ultimately the VA for their funding and development of these devices.

I am a photographer. I don't need to demonstrate that. Obviously, you use your hand for handling cameras, but you use it for many other things, in a darkroom handling paper, handling film, finding slides, a whole host of things.

One indication perhaps of how much this is integrated into my life—there are many psychological reasons—but since the time this has happened, I find that I never, in all the years of dreaming, dreamed that I had only one hand. I think a lot of that can be attributable to the utility of this. Of course, I have adapted to it. I put it on when I get up in the morning and take it off when I go to bed at night. It has become a part of me.

It does many things, and does many things well. But there is great room needed for further work and funding right off. I have all kinds of suggestions that I would like to see them implement in using the hand.

Of course, work in this field depends upon two things in general. I think of advances in science, when we have a power cell the size of your thumbnail that will last a month, where we have material as thin as tissue paper and as strong as stainless steel. We have

made great advances in these things. But right now, with the ability and the materials, with proper engineering we can improve the things we already have just 100 percent.

Let me demonstrate this. We don't realize, I think, those of us who haven't fallen into disability, how much we work bilaterally with both hands. An amputee knows that when he has lost one natural hand the other hand has to take over. In my case my right hand was my dominant hand and the left hand has to do the dextrous things. If I'm changing wiring in a socket, I will hold it with the myoelectric hand and obviously turn the screw with the screwdriver in my left hand.

To anyone who has sprained or broken a wrist, try and tie a pair of shoelaces with one hand. This is the way the myoelectric enables you to do it. [Demonstrating.] It's just about as dexterously as I did with my natural hand, albeit a little bit slower, perhaps.

Days of playing the piano are done for me, but at the initial suggestion of my wife, I type. I was a touch typist and I can type pretty darned fast using this sort of method. I'm still touch-typing with my left and I'm hitting cap keys and things like that with the right.

Mr. EDGAR. How are you controlling that?

Mr. DELLENBACK. I'll take the hand off and show you that.

If I'm doing this [demonstrating], a simple little thing, we use two hands to do that. With one hand, you would have to hunt a place to put it down. Before I take it off, let me show you Northwestern's, to me, magnificent proportional control. If I were to use an instrument such as this, you can see the control I have with that, as delicately, just about as I could with my natural hand. That is a very important feature.

I will show you the workings of this. Actually, I'm off a little bit above the wrist. This portion has atrophied, as most amputees who don't have myoelectric prostheses do. This portion is essentially like my normal hand because I am using the muscles and the circulation in it. You can see the use of my flexers and extenders, the muscles that in your hand control the opening and closing of your hand. This is effectuated by little contact points in the hand that press in against and pick up that minute change in electrical potential upon a signal. Let me show you, in effect, what this does.

This is the closer, here's the opener. I'll show you how the myoelectric hook works. It is quite sensitive. Northwestern has recently developed this interchangeable myoelectric hook with——

Mr. EDGAR. Did you learn to lick that as a photographer?

Mr. DELLENBACK. Well, it's my own arm, and since I take good care of it by washing every night and using alcohol in the socket, I don't think I have any contamination. One just needs a little bit of electrical conductivity to transmit that signal.

Now, the advantage of the hook, one major thing is its extreme speed. I will show you on small items, also, its ability to get in—this is some aspirin tablets or the equivalent. I can handle small things quite well with it. On occasion, because of this proportionality, when I have to, I can exert a certain amount of force with it. [Breaking an aspirin.]

Mr. EDGAR. That's when you really have an Excedrin headache that you do that, right? [Laughter.]

Mr. DELLENBACK. You said it.

Obviously, there's a need for a lot more work in prehension devices, terminal devices, for this, improvements on the hook and its formation, improvements in the performance of the hand because it already has one of the sine qua nons that Dr. Childress has mentioned, that is, its humanoid appearance. This makes a profound difference. When I have a coat on and moving in social circles among strangers, there are very few people who notice I have an artificial hand. Part of that is due to the fact that I'm using it and not going around this way. I am using it in my daily life.

I probably skipped a lot of things, but let me turn the floor over to Tom.

Mr. EDGAR. Thank you very much for doing that. That was very helpful to us.

Dr. CHILDRESS. Tom has an above-elbow amputation, Mr. Chairman.

## STATEMENT OF THOMAS RUTKOWSKI

Mr. RUTKOWSKI. My level of amputation is roughly up here, so the elbow that you see is operating mechanically, but I have the same proportional control of the hand, no matter what position my elbow is in. The elbow is simply a hinge so I can raise and lower the forearm.

I don't have the bag of tricks that Bill does, but there are certain things. If you can envision trying to do this one-handed. I do it unconsciously after a while.

I don't know what else to say, except that we do need a little bit more development of speed and strength in this particular device. I think that can come with research. But such simple things as trying to pick a sliver from under your fingernail is virtually impossible for an upper extremity amputation without an adequate terminal device. The control on it is amazing.

Thank you very much for the opportunity to be a part of this testimony.

Mr. EDGAR. We appreciate your showing us that device and also taking time out of your very busy schedules to be here with us.

I wonder if it might not be appropriate, at least for those of us who have marveled at what you have done, to give you a round of applause, as well as to all those who appeared. [Applause.]

We noticed you were taking that glass of water. That was very good, very impressive. [Laughter.]

Dr. BOREN. Mr. Chairman, this completes our indoor demonstrations. I would like to emphasize our four outdoor demonstrations. They will be the ski-sled and the sports bike that we have seen inside, which will also be outside, and I would like to introduce Mr. Charels Scott, if I may. He will be demonstrating the Scott Van. The demonstrations will be in the horseshoe of the Rayburn Building.

Mr. Scott, do you have any comments you would like to make about the van before people go down to see it?

Mr. SCOTT. Mr. Chairman, members of the committee, we will be presenting two vans which are commercially available. One is a training vehicle for use in evaluation and training of the individual

severely handicapped person. These are all designed to be driven from a wheelchair.

In addition, we will have Mr. Larry Sauer, who is a VA employee, who will present his own vehicle which he drives on a daily basis. So it will give you a little idea of what this means to the individual to have independent transportation.

Thank you.

Mr. EDGAR. Thank you very much.

We are going to be starting in about 10 or 15 minutes at the horseshoe where the two vans are, and jogging from there to the House steps of the Capitol. We are hoping that the bicycle can also go along with us over to the House steps. If there are any photographers who would like to get some pictures of the bicycle in action, as well as the jogging and the Seattle foot in movement, we invite them to come along.

Is there any additional——

Dr. BOREN. Yes. The other person is Dr. Catherine Britell from the Denver VA Medical Center. She will be demonstrating the unistick vehicle controller. She would like to present a few comments about that.

**STATEMENT OF CATHERINE W. BRITELL, M.D., PRINCIPAL INVESTIGATOR, VAMC, DENVER, CO, ACCOMPANIED BY DALE JOHNSON, PRESIDENT AND GENERAL MANAGER, JOHNSON ENGINEERING CORP., BOULDER, CO**

Dr. BRITELL. Thank you.

Mr. Chairman, subcommittee members, I am Dr. Catherine Britell. I am Chief of Rehabilitation Medicine at the Denver VA Medical Center, and assistant professor of Physical Medicine and Rehabilitation at the University of Colorado's Health Sciences Center.

I am the principal investigator for the unistick vehicle controller which is installed in one of the vans that we will be demonstrating to you outside a little bit later. I have passed out to you a written description of our project that you can take along with you.

I would also like to introduce at this time Mr. Dale Johnson, president and general manager of Johnson Engineering Corp. in Boulder, CO, who has been responsible for the engineering development of this system.

I am a medical doctor. I am responsible for the primary medical care of disabled veterans and also for their rehabilitation. Through the years I have been very impressed that many of my disabled veteran patients are most in need of mobility, not only around the room like the things we have seen here this morning, but also about the community, in order to maintain employment and normal functioning in their family and in the community.

In 1973 a young C-4/5 quadriplegic man in Colorado, who really didn't have any way of operating a motor vehicle, asked the following question of some visiting NASA engineers: He asked:

> If astronauts can drive a lunar rover with a joystick with one hand, and I can drive a wheelchair with a joystick with one hand, why can't an automobile be adapted for me to drive like they drive the lunar rover?

As a result of this inquiry by a patient who very much wanted to get back to work with a greater level of independence, a project to develop a driving control system using lunar rover technology,

funded by the VA and managed by NASA, was undertaken at Johnson Engineering Corp. The interim result of this project is the engineering prototype that you will see in a little bit.

The system is unique, in that the functions of steering, acceleration, and braking are easily controllable with one hand by virtually anyone who can manage a joystick control powered wheelchair. In addition, it is controlled by a computer which is programmable to adapt to a wide range of disablities. It is installed quickly, entirely within the passenger compartment of a vehicle, by a regular mechanic. It is easily removeable and reusable, allowing resale of the vehicle, and also maintaining its factory warranty.

One thing that we found while testing this system is that the controls are easy and pleasant to use for lower level handicapped people as well as able-bodied individuals. So, we believe that the system may have broader applications than just for high level quadriplegics.

In conclusion, the unistick vehicle controller has the potential for increasing employability, independence, and self-esteem for many handicapped people in a very, we feel, cost-effective way.

We will be most happy to answer any questions you have in the demonstration period that will follow, and we thank you very much for giving us the opportunity to share this exciting project with you.

Mr. EDGAR. Thank you very much.

Dr. Boren.

Dr. BOREN. We would like to thank Mr. Larry Sauer for driving his own van for the demonstration.

This concludes our demonstrations this morning, Mr. Chairman. We would like to give thanks on the part of the VA for your allowing us to do our presentations this morning. Thank you very much.

Mr. EDGAR. I want to thank you, the VA, and all of the participants today.

It has been brought to my attention that because of improved health care and battlefield evacuation, a larger number of Vietnam veterans sustained and survived more catastrophic injuries, including spinal cord injuries and amputations, than those who served in prior wars. It is our anticipation that the VA, with its research budget and continuing its efforts, perhaps could improve their research in a number of ways, as was urged by the service organizations. We believe that the VA can be at the forefront of new health technology, particularly in this prosthetics area.

This concludes the second of three research hearings. We intend in June to hold a final hearing in a number of important areas of VA research. The three hearings, as a whole, will, I believe, be probably the largest accumulation of VA research testimony that we have received. It will also help to show, I hope, to the general public at large that the VA is at work in a number of important areas to improve health and preventive health medicine in the future.

We will now adjourn these hearings, but really recess them for a few moments, to change like "Superman" into another outfit and to proceed to the horseshoe and then to the House steps for the other demonstrations. I would invite everyone to take part in the demonstrations.

[Whereupon, at 12:15 p.m., the subcommittee was adjourned.]

# APPENDIX

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STATEMENT OF FRANK R. DEGEORGE, ASSOCIATE LEGISLATIVE DIRECTOR

Mr. Chairman and Members of the Subcommittee, Paralyzed Veterans of America appreciates this opportunity to express our views regarding the Veterans Administration's prosthetics and rehabilitation research programs.

Research in this area is of critical importance to PVA's members, all of whom have experienced spinal cord injury or dysfunction. Research in prosthetics and rehabilitation holds for all severely disabled persons the greatest promise for improved physical and emotional well-being.

Mr. Chairman and Members of the Subcommittee, it is impossible for me to begin to express to you the emotions a disabled individual feels when his or her quality of life is assisted through an advancement in prosthetics or rehabilitation research.

As we all know, the Veterans Administration once was clearly the world's leader in prosthetic research: prostheses and orthoses developed by the VA over the years have provided mobility for thousands of disabled veterans, and have enabled many of them to pursue close-to-normal lives after the onset of disabling conditions.

Since World War II, the research efforts of the Veterans Administration have received acclaim. In developing prosthetic devices that have benefitted veterans, the VA has thereby served all of mankind. Between these efforts and those made in the private sector (including PVA's own research activities), there have been significant advances in helping severely disabled persons overcome limitations that arise from their disabilities.

It is because of the great importance that rehabilitation engineering research holds our members, for thousands of other disabled citizens, veterans and civilians alike, and the promise of such research, that we are grateful for this hearing today. PVA hopes that the efforts of the VA will receive greater public and government attention through such hearings. And, it is further hoped that increased resources and emphasis will be directed toward these vital and necessary fields of research.

As has been stated recently to this Subcommittee, one of the mandates of PVA's congressional charter is to promote research, and we take our responsibilities in this very seriously. We are proud of our organization's contributions in the area of prosthetics research.

PVA's Spinal Cord Research Foundation was created in 1976, and at that time was called the PVA Technology and Research Foundation. In the past nine years, our Foundation has awarded more than $2.5 million aimed at prevention of and cure for spinal cord injury, and at care for those who have already experienced SCI. Much of this effort has been dedicated to developing and improving prosthetic devices that assist catastrophically disabled individuals. For example, PVA funded research on a cushion for wheelchair users that reduces the likelihood of decubitus ulcers. As the Members of this Subcommittee know, these ulcers can be life-threatening and often result in lengthy, expensive hospitalization.

Many quadriplegics in the very near future will be able to benefit from PVA-sponsored research on a special hinge which is used in powered wheelchairs. Frequently, high-level spinal cord injuries cause the individual to require reclining during portions of the day, but the movement caused by traditional wheelchairs resulted in their displacement. Such displacement made it necessary for an attendant to be present to assist them. However, the newly-developed hinge allows the individual to recline without displacement, and it is being marketed commercially as a retrofitting device for most powered wheelchairs currently on the market.

Quite clearly, private companies would not have been willing to spend research money for the development of a device that has this limited number of consumers.

Furthermore, PVA is funding promising functional electrical stimulation research conducted by Dr. Robert Jaeger at the Illinois Institue of Technology in Chicago. As we testified before the Subcommittee only a few days ago, one of PVA's ultimate

goals is the cure to spinal cord injury and dysfunction. However, when an individual has been required to use a wheelchair for several years, he or she will most often have lost a sense of balance that is required if that person is to ever walk again. Therefore, Dr. Jaeger's project aims to enable SCI individuals to stand for extended periods of time through the use of functional electrical stimulation, or FES. This research could prove to be invaluable as more progress is made in the area of functional electrical stimulation as it becomes a possible means of walking.

Recreation for the catastrophically disabled person continues to be one of PVA's highest priorities, and we are very pleased to recognize the VA's rising emphasis in this area. The VA now understands the importance of recreation to one's physical and emotional well-being; therefore, each year the VA sponsors wheelchair competitions in a variety of sports. These competitions encourage wheelchair users to develop the physical and emotional attributes necessary to cope with and overcome their disabilities.

The VA Administrator, the Honorable Harry N. Walters, has stressed that competition and recreation are of special importance for severely disabled veterans. To this end, in early 1984 he called together a group of key VA personnel and instructed them that the VA Recreational Service would be adequately funded and that recreational activities would teach skills and instill attitudes that lead to the physical and psychological rehabilitation of severely disabled veterans.

He recognizes that recreational activity helps disabled veterans develop and maintain physical stamina that is especially valuable for them. After all, competition and recreation provide disabled persons an opportunity to overcome some obstacle or to defeat a competitor, and this attitude and ability enables them to overcome their own handicaps. In short, it is essential that severely disabled persons maintain an overall fitness, both physically and emotionally.

It should be emphasized that disabling conditions quickly and continuously worsen if the individual does not make every effort to stay in top physical condition. For this reason, therefore, PVA has been very supportive of the VA's development of a bicycle that enables paraplegics to exercise on a routine basis. While this activity at first appears to be recreational, its ultimate result is improved health-care: muscle tone is greater, circulation is improved, and, as a result, bladder infections are reduced through use of this specially adapted machine.

Furthermore, it is normal for individuals to develop psychological problems after becoming severely disabled, and too many feel that they can no longer withstand life's rigors. Recreation, therefore, offers a competitive and demanding atmosphere in which the physical and emotional difficulties arising from the disability can be minimized.

Since PVA recognizes the importance of recreation, we too, have dedicated funding toward this end. Today, because of our research efforts, paralyzed individuals are able to use a special saddle and thereby ride horses, an avenue of access to the outdoors. Furthermore, since some catastrophically disabled persons maintain a high sense of adventure, we are funding a project which will allow ultra-light airplanes to be adapted for hand controls so that paraplegics can fly them. The controls for this light-weight airplane were modeled after automotive adaptive equipment, a prosthetic device perfected by the Veterans Administration.

Not to be repetitive, but to emphasize a key point, recreation such as horesback riding or piloting a small aircraft builds confidence, and self-confidence is that character element most essential in overcoming the limitations resulting from a severe disability such as spinal cord injury.

As is apparent, PVA and the VA Administrator share a common understanding of the importance of many aspects of rehabilitation, and PVA and the VA have worked closely in the areas of prosthetics and rehabilitation research. Our mutual goal is improving the quality of life for severely and catastrophically disabled individuals. An example of this close working relationship is that both PVA and the VA are participating actively and financially in the development of uniform consensus standards for wheelchairs.

Until recently, there have not been uniform standards for wheelchairs: even though the VA has used specified purchasing criteria when contracting with suppliers for the acquisition of wheelchairs, there has not been an overall quality and performance standard. Therefore, the VA's Office of Rehabilitation Research and Development, PVA, and several wheelchair manufacturers are supporting work of the Rehabilitation Engineering Society of North America's Wheelchair Standards Committee for the establishment and publication of such standards.

This combined effort includes wheelchair manufacturers, engineers, consumers, and other federal agencies, such as the Food and Drug Administration of the Department of Health and Human Services. The result of this effort will be perform-

ance and durability standards for wheelchairs that are acceptable to federal agencies, consumers, and manufacturers alike.

We were especially pleased, recently, when the VA purchased on a research basis Passive Exercise Toning Tables, devices previously used in reducing salons. These motorized tables have the potential for revolutionizing physicial therapy for people who are spinal cord injured or who have multiple sclerosis. They work to tone existing muscle through passive exercise.

Testing of these tables, under medically controlled procedures and research protocol, is necessary to prove or disprove their effectiveness, which is the whole purpose of and procedure for prosthetic and rehabilitation research as conducted by the VA.

There are some important benefits, should these systems prove effective: in addition to improved muscle tone, the potential exists for increasing circulation affecting heart and kidney function, raising calcium levels in bones, and reducing spasticity. The improved circulation, kidney function, and mineral balance will, quite likely, result in fewer cases of bladder infections in SCI veterans—bladder infections is a leading health-care problem for SCI veterans and often results in hospitalization or ends in death. Therefore, the Members of this Subcommittee can readily understand PVA's enthusiasm for these machines and our strong support for the VA's research in this area.

Should these machines be effective, another problem also will have been alleviated: with the shortage of physical therapists throughout the VA system, these tables may provide an answer by reducing the resources needed to perform range of motion and passive exercises. In short, a single therapist can work with several veterans simultaneously, using these machines, whereas presently they work with only one at a time and individual veterans do not receive the services they need.

During the last few years the VA has set the needs of the spinal cord injured as one of the higest priorities for investigation by the VA Rehabilitation Research and Development Service. Products of this high priority have been VA conferences on Wheelchair Standards (1981) and Functional Electrical Stimulation (1982). PVA appreciates the VA's interest in SCI veterans, and we applaud the effort which has been made to design products for use by such individuals.

At least as important as the research is the VA's emphasis on putting such devices into the hands of veterans at the soonest possible date, and we are seeing marked improvement in the application of new technology. One of the most promising developments by the VA in the area of prosthetics research has been the proposed administrative restructuring of various offices that deal with this important area. Presently the Rehabilitation Research and Development Service is part of the Research Service, and fragmentation arises because prosthetics and sensory aids constitute a separate area of research and employs a second set of personnel.

As we understand it, the VA is in the process of establishing the position of Associate Deputy Chief Medical Director for Professional Services, a position which will enable the agency to better coordinate future research efforts. The new ADCMD will coordinate both rehabilitation research and development and the prosthetics and sensory aids service.

PVA discussed with the VA the need for this or a similar reorganizational step, and we are very pleased that the Veterans Administration has taken this action: we are confident that administrative restructuring will lead to better coordination of VA programs. We commend the VA for its cooperativeness and willingness to attempt this change, and we anxiously await its implementation.

Mr. Chairman and Members of the Subcommittee, we are very pleased that PVA has been able to report many positive aspects of the VA's rehabilitation research efforts. Problems do exist, however, that should be brought to the Subcommittee's attention.

First, the VA has gotten away from its original system of a centrally-controlled, nationwide system that was capable of conducting research; designing and engineering prosthetic devices; arranging for production; and training prosthetics personnel, therapists, and medical staff to best assist the user.

At some indefinite time, approximately twenty years after World War II, the VA prosthetic program underwent a change in direction from that previously described. The reasons for this change are obscured in the impact of internal and external policies and attitudes on the program.

The VA program attracted some of the best people in the field because it was the acknowledged worldwide leader in prosthetics. As the program expanded, the intermediate level began to exercise more control and independence. Thie evolution was especially true in the area of research and development.

The result was a gradual shift of central managment control away from the VA Central Office to these programs, and budgetary, personnel, planning, and review

activities were delegated from VACO to intermediate or local levels. The effect of these changes was the fragmentation of the nationwide VA prosthetics program. Some fragmentation, of course resulted from advancing scientific specialization; however, the VA remained without a center of control and, quite importantly, without a central point for dissemination of information.

The National Academy of Sciences, in a 1976 study, noted that the VA and the United States had been the world's leader in prosthetic research, but that role has greatly diminished. PVA maintains that the noted decentralization was largely the cause of ths decline in quality research.

PVA proposes that the VA carry through on the recommendation made by the Director of Rehabilitative Engineering Research and Development: that is, establish in Washington, D.C., a central Rehabilitation Education and Testing Center. That is a very logical proposal and one that should resolve many of the problems that arise from the presently fragmented system employed by the Veterans Administration.

The Washington, D.C., VA Medical Center would be the most appropriate location, since it is already firmly established and is a leading VA medical facility. This VAMC is, quite importantly, located close to the National Institutes of Health, the National Aeronautics and Space Administration, the VA Contract Services, and the VACO itself. Each of these institutions either develops theories and materials that would be useful in prosthetics research or administers essential VA activities. We feel, in short, that VA prosthetic research should not be so fragmented and should be centralized, and the Nation's Capital is the sensible place for a solution to be realized to the existing fragmentation problem.

The second problem with the VA's rehabilitation and prosthetics research program that PVA feels compelled to point out today deals with the VA's two Rehabilitation Research and Development Centers. One center is at Hines VA Hospital in Hines, Illinois, and the other at the Palo Alto, California, VA Medical Center.

These two centers already have conducted valuable research projects, and they offer great potential for improved and expanded research. PVA feels that staffing and funding these cneters should be a top priority within the VA and by the government; however, in recent years a larger percentage of VA funding is going to non-VA conducted projects that are similar to those that could well be performed at the Rehabilitation R&D Centers at Palo Alto and Hines.

As noted, these facilities are already in place and are capable of producing valuable research; therefore, PVA feels that money should be channeled into development and expansion of these two centers, since they are already are integral components of the VA health-care system.

The centers at Hines and Palo Alto contain capable researchers who possess unique abilities, and PVA strongly recommends maintaining these facilities. Given adequate funding, they will develop methods and materials that will benefit millions of severely disabled persons.

In looking at the proposed center for Washington, D.C., and at the existing ones at Hines VA Hospital and Palo Alto VAMC, we recognize that developing these centers would give the VA and the entire country a valuable national resource capable of meeting existing and future needs of disabled veterans.

As has already pointed out, VA research and development that has served veterans has always been used to benefit non-veterans as well. The result of VA research, therefore, is an improved quality of life for all disabled Amercians.

There is little doubt that the Rehabilitation R&D Centers at Palo Alto and Hines constitute potentially some of the most productive efforts by the VA in the areas of prosthetics and rehabilitation research. PVA therefore strongly encourages this Subcommittee and the Veterans Administration to ensure that the centers are adequatley staffed and funded: they form an important part of the VA's research effort. Furthermore, we feel that the Washington, D.C., Center must be established. So that there will be centralized control and information sharing within the VA and between VA and other federal agencies.

VA research has benefitted millions of our nation's veterans, and improvements and discoveries made by the VA have been quickly used by the larger society. In short, it has been so important to the well-being of milions of Americans that we ask this Subcommittee to ensure adequate funding for the VA's prosthetic and rehabilitation resrearch program.

Mr. Chairman and members of the Subcommttee, the importance of the VA's efforts in prosthetics and rehabilitation research cannot be overemphasized. We applaud the VA's continuing concern and commitment in these areas and we hope that such efforts will grow and prosper to the benefit of the nation's veterans and all disabled individuals. We ask the Members of this Subcommittee to keep in mind

that the number of handicapped persons in this country is constantly increasing, and, therefore, the need for expanded prosthetic and rehabilitation research grows.

Even if the nation never again enters into armed military conflict, there will continue to be veterans who are severely disabled in the future—we ask that the VA ensure that these individuals receive the best possible care, treatment, and rehabilitation in the world. The VA, as the coutnry's agency meant to care for those who served the nation, must be given an opportunity to provide that service.

Mr. Chairman, this concludes my testimony and I will try to answer any questions that I can.

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STATEMENT OF DAVID W. GORMAN, ASSOCIATE DEPUTY NATIONAL LEGISLATIVE DIRECTOR, DISABLED AMERICAN VETERANS

Mr. Chairman and members of the subcommittee, on behalf of the 867,000 members of the Disabled American Veterans, including the literally thousands whose disabilities dictate the use of prosthetic applicances and devices, we certainly appreciate this opportunity to discuss the Veterans Administration's research programs on prosthetics and rehabilitation.

Mr. Chairman, before proceeding with the text of my testimony, let me begin by extending to you the DAV's sincere and genuine appreciation for the interest you have exhibited in the area of the VA's research programs.

In conjunction with the VA Department of Medicine and Surgery's (DM&S) mission "to ensure that quality medical care is provided on a timely basis within the law to all authorized veterans' many innovative, exciting and important programs have been established. The DAV is of the firm conviction that within the structure of DM&S the research component may be singled out as one of the vital support pieces.

Mr. Chairman, research is generic to the entire medical community whether it be the private sector or the federal government. However, we believe that were it not for federal government participation, rehabilitation research would be virtually nonexistent in this country.

Virtually all research that is conducted, especially in the private sector, is in the form of medical research. This type of research, although valuable, is tedious, time-consuming, with the possibility of results being found only after years and years of study.

On the other hand, rehabilitation research often produces beneficial results in a comparartively short period of time. This results in disabled veterans, who must endure disabilities for the remainder of their lives, being able to utilize of such research findings in order to lead a fuller, more comfortable and productive lifestyle.

The VA Rehabilitation, Research and Development Service (RR&D) is charged with the responsibility of improving the quality of life and allowing more functionally independent activities of daily living by disabled veterans, through research, development and evaluation of new or unique devices, techniques or concepts in rehabilitation.

In Fiscal Year 1984, the VA's budget authority for research programs was $217.6 million. Of this, $205 million was obligated for medical research as compared to rehabilitative research and development which totaled approximately $10.8 million or about 5% of the overall budget.

Mr. Chairman, in our opinion, the RR&D Service is doing an excellent job in view of what we consider to be inadequate and restrictive funding.

During 1981, Dr. Margaret Giannini assumed the position of Director of the VA's RR&D Service. Since that time, Dr. Giannini has been instrumental in what we consider to be an extremely viable and enthusiastic research effort. Many positive and exciting accomplishments have been witnessed, some of which will be discussed and actually observed here today. Dr. Giannini has the gratitude of the DAV for the accomplishments she has made over the past three years.

However, we are extremely concerned that without adequate funding, the RR&D Service will again be placed in a position of falling behind in meeting the rehabilitative needs of disabled veterans.

Mr. Chairman, we are aware there are a number of very important and meritorious projects that currently require funding support of approximately 43 million which is not now available. This lack of sufficient funding translates into projects being delayed and deferred to future fiscal years and, consequently, any new or increased funding in subsequent fiscal years will be consumed immediately.

The DAV strongly believes that the RR&D efforts in prosthetics cannot be forced to fall backwards or remain stagnant. They must, out of necessity, move forward.

Mr. Chairman, we believe it to be acknowledged by professionals in the field, that there exists today a tremendous need for rehabilitation research. However, the urgency of this need increases substantially when considering the needs of the aging veteran.

You, Mr. Chairman, as much as anyone, realize the tremendous impact and demand for services that the aging veteran will place on the VA medical care system within the next few years.

Recognizing that prosthetic research is a priority within RR&D, and that approximately 40% of available funds are dedicated to this purpose, consider the following: In FY 1980, 4,938 amputations were performed within the VA medical care system; in FY 1982, 6,230 amputations were performed within the VA stystem; a conservative estimate may be that between 80% to 90% of all amputations performed by the VA were done because of ischemic and occlussive arterial disease (peripheral vascular disease, PVD); and the aged veteran population will only serve to increase this already statistically massive health concern.

VA sponsored research efforts in the area of PVD have salvaged many ischemic limbs and, when amputations were necessary, made possible those amputations at a lower, thus more functional level. Additionally, surgical and post-surgical techniques have been refined to the point where early fitting of a prosthesis has been possible.

The cost effectiveness of these techniques and the positive impact on the quality of life for thousands of veterans, usually older veterans, includng the diabetic who are statistically subject to the ravage of PVD, can hardly be estimated.

However, more needs to be done. The amputee, physician and prothetist are confronted with many problems for which solutions are not yet available.

Mr. Chairman, the RR&D Service has recently conducted a series of workshops directed at priority areas that will best meet the needs of disabled veterans.

During April, 1983, the DAV was pleased to host a VA sponsored RR&D workshop on prosthetics and orthotics attended by approximately 70 experts in the field. That workshop updated and expanded the areas of concern in prosthetics/amputation research such as: Development of new casting and fitting techniques for lower extremity amputees to measure the overall stump/socket interface for improved comfort, reduction or elimination of irritation, ulcers, or skin breakdowns; interface material, between the stump and prosthesis, must be devleoped or improved for optimal comfort—new and lightweight materials used to fabricate a prosthesis must be found to minimize (especially in the geriatric veteran) energy requirements thus allowing for associated disabilities such as cardiovascular or pulmonary disease; and for the more active amputee, recreational/sport prostheses and components must be improved or developed.

Mr. Chairman, research in these areas is being done, however, an expansion of effort and additional studies are necessary to achieve the desired results in an expeditious manner.

New fitting techniques are being explored via a computer-assisted design/computer-assisted manufacture (CAD/CAM) process. While VA witnesses will be able to describe the technical aspects of this revolutionary process, a simplifed explanation is that when the veteran has been properly cast and fitted for a new prostheses, the results would be entered into a computer. With computer assistance and the stored information, a socket could be manufactured in a matter of minutes. After wearing the socket, the veteran would be able to identify any problem areas such as pressure points and they would be entered into the computer for correction. A corrected socket would then be manufactured, again with computer assistance. This process would continue until the optimal fitting and comfortable socket were achieved.

For an amputee, the most vital feature of a prosthesis is comfort. If the limb is comfortable, then it is functional.

Mr. Chairman, durng September, 1981 the General Accounting Office (GAO) released a report on amputees and the use of artificial limbs. The report was requested by several Congressmen who were concerned that many veterans endured years of frustration and pain because the prosthetic industry had fallen behind the times, medical personnel had not kept abreast of the latest surgical procedures, or prosthetic professionals and manufacturers had not received adequate training.

One segment of the GAO report was titled, "Amputee Experience and Problems with Artificial Limbs." Under that heading, GAO reported:

Surgeons on the Committee on Orthotics and Prosthetics of the American Academy of Orthotic Surgeons told us that amputees will have problems with their prosthesis and some amputees would never be satisfied.

The Chairman of the Department of Prosthetics and Orthotics at New York Univesity emphasized . . . (1) discomfort is a normal part of wearing an artificial

device; (2) stump changes continuously affect the device's fit; and (3) artificial limbs can be annoyingly heavy.

Simply stated, Mr. Chairman, it was accepted that amputees who wear prostheses will suffer some degree of physical pain and discomfort.

Considering the technology we have today in this country, we find those statements very disturbing and, frankly, inexcusable.

Expansion of the CAD/CAM procedure would, in our opinion, serve to alleviate a significant degree of this seemingly massive problem.

During March of this year, I had the opportunity to personally visit the Prosthetics Research Study (PRS) in Seattle, Washington, under the direction of Dr. Ernest M. Burgess, recently appointed as a VA Distinguished Physician.

PRS is funded entirely by RR&D as an ongoing research project in prosthetic development and is comprised of the Director and two Research Prosthetists. It was indeed a pleasure to observe, first hand, what these individuals have and are accomplishing in the way of innovative prostheses and prosthetic components.

Perhaps the most widely known innovation to emerge from PRS recently is the "Seattle foot." This foot, still in the development and refinement stage, has produced a new feeling of excitement in the prosthetics field due to its functional value.

Mr. Chairman, I am currently wearing two of these feet and can personally attest to their excellence over any other prosthetic foot that I have used. They have permitted me, for the first time since losing my limbs in 1969, to be able to actually run with a degree of comfort.

The technical description and properties of the Seattle foot is best left to the engineers and professionals who have that knowledge. However, no one but an amputee could describe the feeling of being able to run, jog, play basketball, racquetball, or engage in numerous other activities. A non-amputee is unable to describe or measure the feeling of the new-found freedom to engage in activities that have eluded them since their amputation occurred.

Without meaning or wanting to sound overly dramatic, Mr. Chairman, an amputation changes one's life and the development of devices such as the Seattle foot likewise changes an amputee's life.

Unfortunately, only a handful of these feet have been issued to veterans. Further refinement is needed which requires the commitment of continued funding by RR&D. We are hopeful that this particular project will receive the funds necessary to make the Seattle foot the optimal foot for the amputee veteran.

Mr. Chairman, RR&D is also funding a number of projects that are directed toward improving the lives of veterans with disabilities other than amputations. Exciting research is ongoing in the area of spinal cord injury, blindness and hearing impaired veterans. Many of the accomplishments made in these areas will be demonstrated here this morning.

Earlier, Mr. Chairman, I alluded to the level of funding for the VA's medical research service. The DAV supports the VA's efforts in this area as the results have benefited not only veterans, but the entire population, in the understanding, prevention and treatment of various diseases. Such research has not, however, been confined to diseases that are entirely common or prevalent to the disabled veteran.

There is no doubt as to the importance of medical research, however, how do we explain to an elderly veteran that no new developments are underway to make a lightweight prosthesis that would enable him to walk with the least degree of effort, while research money has been provided to study the decreased eyebrow-raising by schizophrenics during an interview situation. Or how do we explain to an amputee that can't obtain a comfortable fitting prosthesis that computerized fitting may be possible in the future when funds are available, when the VA is funding research to determine the effects of high and low nicotine cigarettes on male beagle dogs. Or how do we explain to a young, enthusiastic amputee who wants to participate in as many sports and recreational activities as possible that such prostheses have not yet been perfected due to the lack of adequate funding, while research regarding the learned taste aversion in man is ongoing.

Mr. Chairman, not only could I not answer those questions, I would not want to be put in a position where I would be asked them.

#### AN OVERVIEW OF THE VA'S PROSTHETIC AND RESEARCH PROGRAMS DEVELOPMENT

Prior to 1945, the responsibility of furnishing prosthetic appliances was delegated to different elements within the VA, none of which had overall responsibility for the program. The Prosthetic Program itself was entirely inadequate to meet rapidly growing needs and demands of seriously disabled veterans being released from military service during the World War II era.

Mr. Chairman, the VA's involvement with prosthetic research began at the end of World War II with the birth of the Prosthetics Research Program. From 1945 to 1947 the program was funded by the Office of Scientific Research and the War Department and received technical directon from an Advisory Committee of the Natonal Academy of Sciences-National Research Council (NAS-NRC).

In 1947, the VA assumed funding for the entire program which was managed by the Research and Development Divison of the Prosthetic Service in the Department of Medicine and Surgery.

During December, 1945, Public Law 268, 79th Congress, was approved. Now codified as Section 5013, Title 38, United States Code, this legislation gave the VA broad authority to provide prosthetic applicances ". . . by purchase, manufacture, contract or in such other manner as the Administrator may determine to be proper, without regard to any other provision of law."

Recognizing the need for a viable and ongoing research program, the 80th Congress passed Public Law 729 during June, 1948 specifically authorizing $1 million a year for the Prosthetic Research Program. The VA operated under these constraints until the passage of P.L. 87-572 during August, 1962 which removed the $1 million ceiling and allowed the appropriation of funds as were necessary to conduct the program.

With the enactment of these laws, it was possible for the VA to establish itself as the world leader in the field of prosthetics. The new developments, innovations and improvements made in the field of prosthetics following World War II were indeed impressive.

However, during 1973 with the completion of a major reorganization that totally restructured the entire VA Prosthetic Program, a change for the worse occurred. Prior to 1973, the Prosthetic and Sensory Aids Service (P&SAS) provided for clinical prosthetic services delivery; Research and Development Service managed the R&D Contract Program and; the Education and Training Division conducted continuing prosthetic programs.

As a result of the 1973 reorganization, the P&SAS was placed under the direct jurisdiction of the Assistant Chief Medical Director (ACMD) for Professional Services, the research component was transferred to the ACMD for R&D and the Education and Training Division was the responsibility of the ACMD for Academic Affairs.

Mr. Chairman, it is due to this reorganization within DM&S that has caused a fragmentation of the VA's prosthetic activities and proved harmful to the overall program. This fragmentation still exists today. We are unaware of any significant coordination or direct involvement between Rehabilitation Research, P&SAS, or Academic Affairs for the training and continuous education in the areas of prosthetics and rehabilitation.

We believe that the original reasons for consolidating the Prosthetic Services under a single program are as valid today as they were in 1945.

Accordingly, we have requested the Administrator to consider a reorganization within DM&S to once again form a separate and distinct service that would place RR&D, P&SAS, as well as other rehabilitative services (spinal cord injury, blind rehabilitation, speech and audiology service) and an education and training component under the jurisdiction of a single and newly created ACMD for Rehabilitation, Prosthetic Services and Associated Research and Development.

To fully illustrate our position on this subject and offer suggestions on how it may be accomplished, I would like to submit, for the record, various correspondence we have forwarded to the Administrator.

Mr. Chairman, we would request that, following the Subcommittee's review of this material and if you agree our proposal has merit, you pursue this matter with the Administrator. Additionally, we would ask that you consider the feasibility of legislative action to create such an ACMD.

### PROSTHETICS EVALUATION, TESTING AND INFORMATION CENTER (PETIC)

Formerly known as the VA Rehabilitation Engineering Center (VAREC), PETIC is charged with the responsibility of providing veterans—on a nationwide scale—prosthetic and sensory aids; performing tests on new devices in the filed; and evaluating and testing commercially available devices for handicapped veterans. PETIC also serves as a focal point for gathering and disseminating prosthetic and orthotic devices, as well as sensory aids to VA Field Stations and other organizations involved in rehabilitation.

Originally established in 1959, the Center, located in New York City, was designed to serve as a national referral center for veterans who have special or difficult prob-

lems in being fitted for prosthetic or orthotic devices. Additionally, PETIC provides, through the Orthopedic Footwear Service, orthopedic shoes to veterans nationwide.

Mr. Chairman, PETIC (VAREC) has been a source of controversy for many years. Indeed, it has had and continues to have problems in fulfilling its mission to disabled veterans.

The VA is currently in the process of establishing Special Teams for Amputation, Mobility, and Prosthetics/Orthotics (STAMP). Similar in scope to the Special Clinic Team at PETIC, STAMPs will be designed as multi-disciplinary teams whose mission will be to provide the highest quality service for veterans with amputations and otherwise impaired mobility or limitation in self-care that can be lessened or overcome by the use of prosthetic and orthotic devices; or by other rehabilitation engineering techniques.

Five STAMPs will be established at selected VA medical centers nationwide with PETIC designated to serve the Northeast region of the country.

We are now forced to raise the question—what exactly is the function of PETIC?

We know it has been designated as a national referral center for veterans who present difficult prosthetic and orthotic problems. In other words, the capabilities should exist for any veteran, wherever he/she may reside, to be referred to PETIC for evaluation and fitting of a prosthetic/orthotic device. But this is not done on a routine or consistent basis. In fact, virtually all veterans seen at that Center reside in the immediate metropolitan New York area.

Mr. Chairman, we have presented our views on this subject to the Administrator and asked specific questions regarding PETIC. As of yet, we have not received a satisfactory response.

Contained in the material to be submitted for the record are our views and concerns regarding the operation and function of PETIC. As with the issue of reorganization, we would respectfully request the Subcommittee to review this issue also.

I also wish to point out, Mr. Chairman, that we concur with the Administrator that a National Center of Excellence in Prosthetics/Orthotics should and must exist. In this regard, we offer the following recommendations. First, PETIC should be relocated outside of the metropolitan New York area. We suggest that it be reestablished at a location that possesses the capabilities to provide direct patient care, direct prosthetic services and a research component. Additionally, an active affiliation with not only a medical school, but a school of engineering and a university with an active prosthetic training program would also seem vital.

As a suggestion, Mr. Chairman, Hines VA Medical Center (Chicago) would seem a logical choice. This VAMC offers all components necessary to make PETIC a viable program with the additional attraction of also having a VA RR&D Center.

When discussing the VA's RR&D Program it is necessary to address other issues and services as we have briefly done herein.

It is our option, Mr. Chairman, that only through adequate funding, and direct day to day coordination of services under the direction of one individual, an ACMD for Rehabilitation, Prosthetics Services and Associated Research and Development, will these vital programs be allowed to flourish.

Mr. Chairman, this concludes my statement. Again, I wish to thank you and the Subcommittee for permitting us to share our views on this vitally important subject.

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DISABLED AMERICAN VETERANS,
NATIONAL SERVICE AND LEGISLATIVE HEADQUARTERS,
*Washington, DC, March 29, 1984.*

Mr. HARRY WALTERS,
*Administrator, Veterans Administration, Washington, DC.*

DEAR MR. ADMINISTRATOR: The purpose of this letter is in reference to the Disabled American Veterans continuing concern over the state of the Veterans Administration's Prosthetics and Rehabilitative Research Services.

We have recently had the opportunity to review the Administration's concept and proposed plan for the reorganization of the Prosthetics Program.

As currently constructed, we see certain flaws in the design of the reorganization plan that will, if implemented, fail to accomplish the purpose and goals on which the reorganization plan was originally based.

Under the plan, the organizational sturcture would place the various elements into three major lines of functional acitivity—clinical care, technology development and research. Each activity would receive direction from and be accountable to a Deputy Assistant Chief Medical Director (DACMD) for Prosthetics and Research Technology (P&RT). Additionally, the DACMD would also serve as Director of the Technology Development Service. In turn, and as currently exists, the ACMD for

Professional Services would be responsible for the day to day administration and operation of the entire service.

Our concern is twofold: (1) that the Director of Technology and Development Service (DTDS) will serve both in the capacity as DACMD and as the DTDS; and (2) that the proposed DACMD for P&RT will be responsible to the ACMD for Professional Services. Permit me to discuss first our concern regarding the DTDS/DACMD dilemma. By being responsible for the supervision of the Directors of Prosthetic and Sensory Aids Service and Rehabilitative Research Service, as well as serving as the Director of the fundamentally vital Technology Development Service, sufficient devotion to each will not be achieved. Simply stated, one individual cannot wear several different hats and be loyal to all.

Accordingly, we recommend that the same individual not be assigned to direct these separate and distinct entities but, rather, a qualified individual with appropriate credentials, be appointed to oversee and direct the function of the Technology Development Service.

The second area for discussion is the DAV's grave reservations of assigning responsibility for the administration of this service to an individual or individuals who are currently functioning in an administrative role for the various components of the Rehabilitative Services, specifically, the ACMD for Professional Services.

The services to be dispensed via this type of restructuring will be provided to severely disabled service-connected veterans who have every right to expect to receive the highest caliber of services available. I am sure, Mr. Administrator, the agency has these same expectations and would want to employ every mechanism available to meet the needs of eligible veterans.

The ACMD for Professional Services is currently responsible for the administration of 21 separate services. The DAV is not optimistic that the degree of devotion and commitment that is necessary to inusre success will be directed to the reorganization of these various elements. Frankly put, under the current structure and leadership of top level DM&S management, the VA Prosthetics Program has been allowed to flounder. In our view, it is highly unlikely that simply restructuring the lines of communication will result in a new commitment to the needs of the Prosthetics Program. A different jockey will not make the horse run any faster.

If the new mission statement is to be met—that is, "the goal of the VA's programs in prosthetics is to deliver the highest quality of care and to take the lead nationwide in the development of new and better devices and services"—then placement of an energetic, dynamic and totally devoted individual with a combined knowledge and background in prosthetics, as well as rehabilitative research, is vitally important.

Mr. Administrator, in our opinion, in order to witness the attainment of the goals envisioned by the reorganization plan, affirmative action with respect to the matters discussed herein, is imperative.

As always, thank you for your attention to the above and I look forward to a timely response.

Sincerely,

CHARLES E. JOECKEL, Jr.,
*National Director of Services.*

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VETERANS' ADMINISTRATION,
OFFICE OF THE ADMINISTRATOR OF VETERANS AFFAIRS,
*Washington, DC, April 27, 1984.*

Mr. CHARLES E. JOECKEL, Jr.,
*National Director of Services, Disabled American Veterans, Washington, DC.*

DEAR MR. JOECKEL: Thank you for your letter of March 19, 1984, expressing the concerns of the Disabled American Veterans about the proposed Prosthetics reorganization plan. After considering your comments, as well as those of many others, I have instructed the Department of Medicine and Surgery to proceed with implementation of the plan. I have taken your suggestion that the Deputy Assistant Chief Medical Director for Prosthetics and Technology Development and the Director of the Technology Development Service be full-time commitments. Consequently, each of these positions will be filled by a different individual. I believe, however, that the Prosthetics program most properly belongs in Professional Services, as the program is so intimately interrelated with other clinical care services. Therefore, I have directed that the program be headed by a Deputy to the Assistant Chief Medical Director for Professional Services, as called for in the proposal.

I believe this organization alignment will allow for the administrative attention the program deserves. You can be assured I will give it my continued personal attention.

Thank you for bringing the concerns of your organization to our attention.

Sincerely,

HARRY N. WALTERS,
*Administrator.*

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FEBRUARY 2, 1984.

Mr. HARRY N. WALTERS,
*Administrator, Veterans' Administration, Washington, DC.*

DEAR MR. ADMINISTRATOR: Recently, I had the opportunity to visit the VA Regional Office at 252 Seventh Avenue, New York. I met with Acting Director, Bob Van Sprang, visited various VA sections within the building and held several meetings with DAV personnel located on the 12th floor.

Mr. Administrator, I must report to you that the condition of the New York City VA Regional Office is appalling and an embarrassment to the Veterans Administration. Aside from the roaches and mice which have made a home at the facility, the building is dirty, in desperate need of painting and general repairs too numerous to mention. In my opinion, these conditions are counter-productive to the mission of the VA. I am sure that they have an adverse impact on morale and productivity.

Over the past several years, our National Service Office staff has made repeated requests to VA and GSA officials for assistance. Requests have been made for such things as regular floor cleaning service (presently an annual event), window cleaning service (last cleaned five years ago) and painting—which resulted in one wall painted a year ago.

Further, each of our employees indicated apprehension over violent events that have taken place at the VA Regional Office over the last several years. For example, just four days prior to my visit an attempted rape occurred in the ladies room across the hall from our office. On several occasions DAV employees have been physically attacked by claimants—the last occurred on January 6, 1984. I am enclosing documentation of these events.

VA officials have responded by stepping up visits to the DAV office by their contract guards to twice daily and invited our employees to rape prevention classes. These actions, however, do not solve the problem of employee safety at the VA Regional Office.

Accordingly, I would make the following recommendations regarding the condition and security of the building:

1. Given its present dilapidated state, VA should seek new office space in New York City;

2. If relocation is not possible, every effort should be made by VA and GSA officials to renovate the present space and consolidate VA functions to a fewer number of floors within the building;

3. GSA should be required to provide the services that they have assured can be better, cost effective and more efficient through contracts with the private sector;

4. Further, I would respectfully request, in the event the VA Regional Office cannot be relocated, that our office on the 12th floor be equipped with an emergency duress alarm as was provided to the Veterans Service Division located on the 10th floor. In this connection, I am enclosing a copy of our request dated August 17, 1982 to the VA for the emergency duress alarm system. To date, we have not received a reply.

As I understand it, the Veterans Administration must contract for guard service at the VA Regional Office and that very limited funds are available to provide adequate security and alarm service to the DAV. If such is the case, I would very much appreciate receiving an estimate of the cost of installation of the emergency duress alarm system allowing us to investigate the possible alternatives.

Mr. Administrator, I am sure you are aware of our concern for the safety of our employees. But I do want you to know that DAV personnel are very isolated on the 12th floor at the VA Regional Office. The other two Veterans Service Organizations close their offices at 12 noon daily and the Veterans Service Division frequently refers veterans to our office.

I sincerely believe the VA must assume some responsibility for both the condition of the building and the safety of our employees. I, therefore, strongly urge you to take immediate action to resolve the concerns I have raised.

Thank you for your kind attention to this request.
Sincerely,

CHARLES E. JOECKEL, Jr.,
*National Director of Services.*

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VETERANS' ADMINISTRATION,
OFFICE OF THE ADMINISTRATOR OF VETERANS AFFAIRS,
*Washington, DC, March 26, 1984.*

Mr. CHARLES E. JOECKEL, Jr.,
*National Director off Services, Disabled American Veterans, Washington, DC.*

DEAR MR. JOECKEL: Thank you for your observations and recommendations concerning the Veterans Administration's Prosthetics Evaluation, Testing and Information Center (PETIC), located at the New York VA Regional Office.

I presently have this matter under intensive review, and as soon as a decision is reached as to how the Veterans' Administration can improve its delivery of services to disabled veterans, I will write to you again. I expect to be able to provide you a full response within 30 days.

Sincerely,

HARRY N. WALTERS, *Administrator.*

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MARCH 8, 1984.

Mr. HARRY WALTERS,
*Administrator, Veterans Administration, Washington, DC.*

DEAR MR. ADMINISTRATOR: As you know, I recently had the opportunity to visit the Veterans Administration Prosthetics Evaluation, Testing and Information Center (PETIC) located at the VA Regional Office, 252 Seventh Avenue, New York, New York.

In this connection and in line with our several discussions concerning the state of the VA's Prosthetic Program, I am pleased to apprise you of our fidings relative to the function, mission and our proposal regarding the VA's overall initiative for prosthetics and orthotics.

As I described in my letter to you dated February 2, 1984, the VA's facilities at 252 Seventh Avenue, New York, New York are appalling and an embarrassment to the VA. The physical facilities for PETIC are no exception. Let me state quite frankly, Mr. Administrator, that . . . if PETIC is a national program serving America's ambulatory impaired and amputee veterans, than it is also a national disgrace.

The 1950's vintage surrroundings place veterans waiting for service just 20 feet from the prosthetists' working area—which is unclean and dust-ridden. These unsanitary conditions leave veterans who may suffer open ulcers and stump lacerations vulnerable to, at least, infection.

The work area for the footwear and artifical eye services is in dire need of remodeling. Either the roof leaks or the piping is such that water drips onto the floor. Little puddles seem to collect in this area where the VA maintains its prosthetic "lasts," etc.

Knowing that your staff has already visted PETIC and the New York VA Regional Office, I need not embellish further upon the deplorable condition there. Instead, please permit me to share with you the following recommendations and proposals for your consideration.

1. *Relocation.*—PETIC must be physically relocated from its current location. Although well aware of the recent reorganization which places PETIC under the direction of the Prosthetic and Sensory Aids Service at VA Central Office, our feelings remain unchanged. The current facility is totally unacceptable as concerns the needs of the veteran clientele it is mandated to serve. Additionally, it is questionable if the facility, located anywhere in New York City, would prove readily accessible to veterans from the Northeastern region—those PETIC is mandated to serve. PETIC has not fulfilled its original mission—to serve as a national referral center for complicated orthopedic problems. Conversely, its record of treating referrals from other medical facilities nationwide is dismal, if not almost totally nonexistent. This is not to infer incompetence or lack of ability on the part of the staff, but reflects an absence of referrals from other medical centers predicated I believe, on the location of the facility.

2. *Restructuring.*—A major restructuring within the Department of Medicine and Surgery is needed to effectively administer the various programs associated with the function of the combined efforts of PETIC, Prosthetic and Sensory Aids Service, Re-

habilitation Research and Development, as well as the other professional services designed to meet the needs of the service-connected disabled veteran. To accomplish this, we advocate the establishment of a new, additional and completely autonomous service within DM&S. This can be achieved by the creation of an Assistant Chief Medical Director designated as "ACMD for Rehabilitation, Prosthetic Services and Associated Research and Development." Not only is such a proposal permissible under current statutory restraints (Section 4103, Title 38, USC), it appears morally mandated. The disabled veteran population that stands to benefit most from such a service is the severely disabled combat amputee/mobility impaired, paraplegic, blinded and other seriously disabled veterans. Creation of such a unique service, with a parochial mission, will serve the veteran who has sacrificed the most while, at the same time, benefiting all disabled veterans—and accomplished at no expense to existing programs. Additionally, the fragmentation of services to veterans availing themselves to prosthetic services will be completely or significantly diminished by having all such services under one umbrella of administrative control. (See attached proposed plan for reorganization.)

3. *Footwear service.*—The Orthopedic Shoe Program currently located at PETIC has proven successful in meeting the needs of eligible veterans. Therefore, with some caveats, we suggest maintaining this service at its current location. While adequately addressing the needs of veterans, the Footwear Service must immediately undergo renovation to provide adequate space and, of utmost importance, a clean and healthy clinical atmosphere. The proximity of the last work area and the patient wating area creates a breeding ground for potential infection and/or adverse health effects. Recent research has produced a clinical state-of-the-art procedure for computer-assisted design and computer-assisted manufacturing (CAD-CAM) of lasts that produce the optimal orthopedic footwear available. Because of the highly skilled footwear service unique to the Manhattan, New York Area, we do not recommend the relocation of the VA Footwear Service at this time. Rather, we urge the VA to continue in its CAD-CAM research and that such research be given high priority within the Rehabilitation Research and Development Program headed by Dr. Margaret Giannini. As you know, (hand) cobblers are a dying breed and we cannot expect the VA's current Footwear Program to continue to attract and retain these highly skilled individuals—attrition alone could bring the demise of this needed program.

The CAD-CAM research will eventually erase the need to maintain burdensome and unneeded lasts for the lifetime, and beyond, of the veteran. In this vein, we suggest that procedures be implemented between DM&S and the Department of Veterans Benefits (DVB) to ease the problem of last retention at PETIC. DVB should be able to notify DM&S (PETIC) upon the death of a veteran who is known to have a disability that required orthopedic footwear. Computerized notification should be available to DVB to insert into veterans' claims folders whereupon their demise, PETIC would be notified and the last destroyed. Initiation of such a procedure would release valuable space now used for storage of lasts that could be better utilized.

Mr. Administrator, in my opinion, it appears imperative that frank and candid discussions must commence regarding the concerns raised in this letter. Therefore, we suggest a meeting be scheduled between responsible VA Central Office officials and interested veterans' service organizations. Via this vehicle, it should be possible to come to a mutually satisfactory resolution to a problem we feel is of tremendous importance.

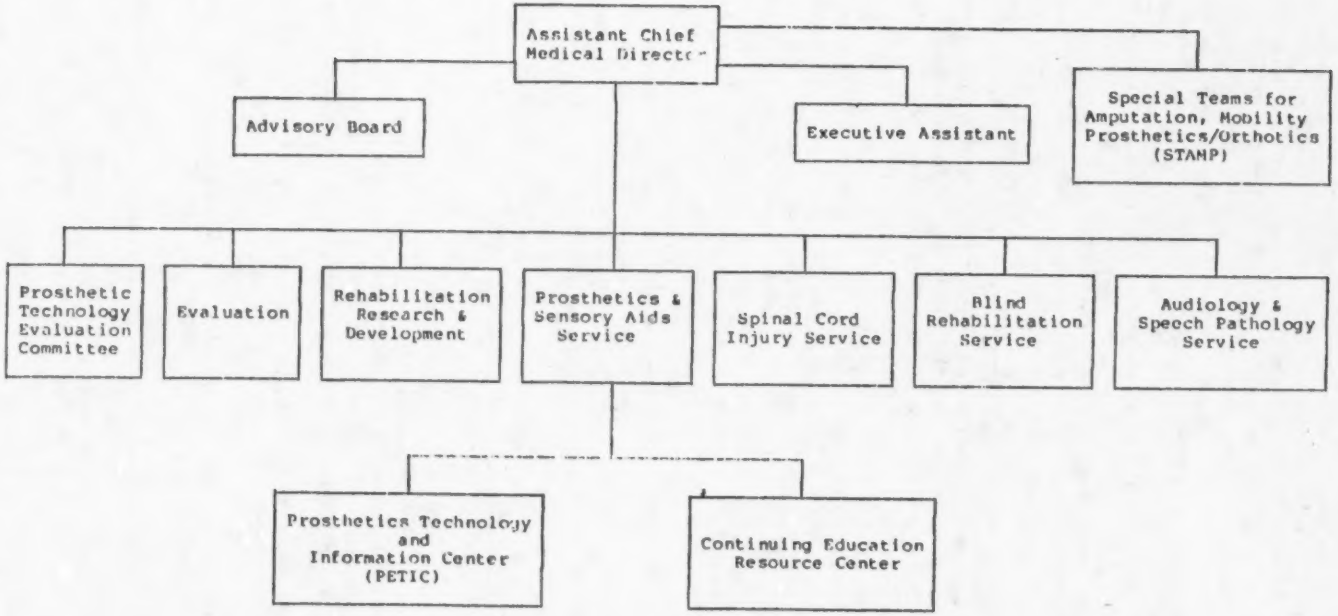
I have enclosed a series of articles that appeared in DAV Magazine during 1982 pertaining to the VA's Prosthetics, Research, Engineering and Development Program. I am sure you will find these interesting and informative.

As always, I thank you for your attention to the above and I look forward to a timely response.

Cordially,

CHARLES E. JOECKEL, Jr.,
*National Director of Services.*

Enclosures.


Assistant Chief
Medical Director
Advisory Board
Executive Assistant
Special Teams for Amputation, Mobility Prosthetics/Orthotics (STAMP)
Prosthetic Technology Evaluation Committee
Evaluation
Rehabilitation Research & Development
Prosthetics & Sensory Aids Service
Spinal Cord Injury Service
Blind Rehabilitation Service
Audiology & Speech Pathology Service
Prosthetics Technology and Information Center (PETIC)
Continuing Education Resource Center

A. CRITICAL SERVICE

PSAS

| | Organization | Location | Time |
|---|---|---|---|
| Prosthetic/Orthotic Labs | | | |
| Restoration Clinic | | | |
| Special Clinic Team | | | |
| Centralized Shoe Program | | | |

TDS

Information and Education Service

Research and Development Service

TAPES

Questions: Final Organizational Structure

Physical Location of Unit

Time of Move

B. Necessary Routine Day-to-Day Functions:

Daily operations must continue.

Improve morale, provide job assurance.

Position management and classification.

Recruitment and Placement.

Labor and Employee Relations.

Systems.

C. Provide Leadership

Fill
~~Establish~~ Temporary Director Position (Management Oriented)

Fill
~~Establish~~ Deputy Director or Assistant to the Director (Technically Oriented).

PROSTHETICS PROGRAM REORGANIZATION—BRIEFING FOR THE ADMINISTRATOR

Our initial presentation several weeks ago addressed VAREC and the changes proposed for that one element of the Prosthetics program. A critical focus of concern was the mechanism by which new devices and procedures are identified, developed, tested and evaluated, and ultimately brought on line. Following your guidance, we have reassessed the total program in Prosthetics, along with the organizational changes needed to make it more effective.

The new mission statement is given on the first slide:

> The goal for the VA's programs in prosthetics is to deliver the highest quality of care and to take the lead nationwide in the development of new and better devices and services.

To achieve this goal, the following objectives must be met:

> Provision of direct patient services that are prompt, considerate, and of the highest quality (Patient Service);
>
> Maintain a supply pipeline that ensures availability of the needed devices at the point of service (Supply Pipeline);
>
> Conduct research and development to meet the unmet needs by bringing new and better devices, procedures, and techniques on line (Research and Development);
>
> Maintain a well-trained staff at all levels, and provide for their continuing education and training (Training);
>
> Manage the entire program in the most efficient and effective way (Program Management);
>
> Utilize funds in the most effective and efficient way, and, when necessary, successfully petition for any additional funds needed to fulfill the other objectives (Resource Utilization).

It is apparent that a wide range of programs, skills, and abilities are needed to carry out the total program and meet the objectives. At present, these are vested in different offices, and there is no control point at the top whose sole function is to direct the program. Our proposal is intended to establish that control point, and to provide for the necessary integration of program elements with parallel and overlapping functions.

The next slide diagrams the building blocks from which, after modification, the new structure will be developed. The letters R, CC, and TD stand for Research, Clinical Care, and Technology Development, respectively, and identify the primary mission of each element.

The organizational alignment shown on the next slide regroups these elements by functional activity into three major lines, Clinical Care, Technology Development, and basic Research. Each line would report to and receive direction from a single position, the Deputy ACMD for Prosthetics and Research Technology. The entire structure would be under the ACMD for Professional Services. This would maintain a close alignment of the Prosthetics program with the clinical services which are the predominant users of the output of the Prosthetics program. In turn, the research and development activities are driven by the clinical need.

The deputy would supervise the Directors of the Prosthetic and Sensory Aids Service and the Rehabilitation Research Service. He/she would also serve as the Director of the Technology Development Service to ensure that the output of both basic research and commercial development were fed into the development line, and that the Services' activities responded to the clinical need.

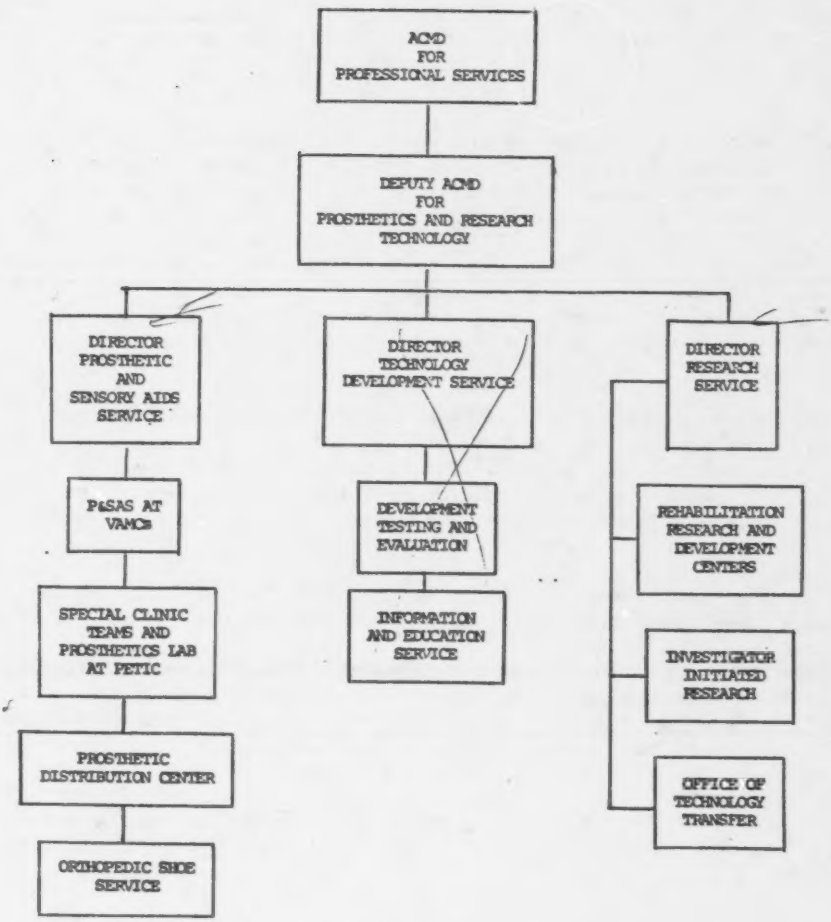
The Director of the Rehabilitation Research Service would direct programs for basic and clinical research into new devices and procedures.

The Director of the Prosthetic and Sensory Aids Service would direct all program elements providing direct patient care, i. e., the Prosthetic and Sensory Aids Services at the VA medical centers and the special clinical services at PETIC. In addition, he/she would assume direction of the Prosthetic Distribution Center. This is a unique aspect of the Supply Service, as it is dedicated solely to support the Prosthetics and Sensory Aids programs. In addition, it is the only Supply Service program that issues supplies and equipment directly to patients.

To summarize, the proposal would bring the critical components of the Prosthetics program under a single control point. At the same time, it would consolidate efforts at development, testing, and evaluation of new products. Close coordination would be achieved between the major lines of patient care, technology development, and research. The most important single factor would be the qualifications of the Deputy ACMD for Prosthetics and Research Technology. He/she should have background experience in clinical prosthetic care and in research to supervise the directors of these lines. He/she must also have the ability to aggressively and successfully manage the Technology Development program. We would begin recruiting for such a person as soon as we have your approval.

Harold E. Booker, M. D.
Deputy ACMD
for Rehabilitation Services

March 15, 1984


ACMD
FOR
PROFESSIONAL SERVICES
DEPUTY ACMD
FOR
PROSTHETICS AND RESEARCH
TECHNOLOGY
DIRECTOR
PROSTHETIC
AND
SENSORY AIDS
SERVICE
DIRECTOR
TECHNOLOGY
DEVELOPMENT SERVICE
DIRECTOR
RESEARCH
SERVICE
P&SAS AT
VAMCs
DEVELOPMENT
TESTING AND
EVALUATION
REHABILITATION
RESEARCH AND
DEVELOPMENT
CENTERS
SPECIAL CLINIC
TEAMS AND
PROSTHETICS LAB
AT PETIC
INFORMATION
AND EDUCATION
SERVICE
INVESTIGATOR
INITIATED
RESEARCH
PROSTHETIC
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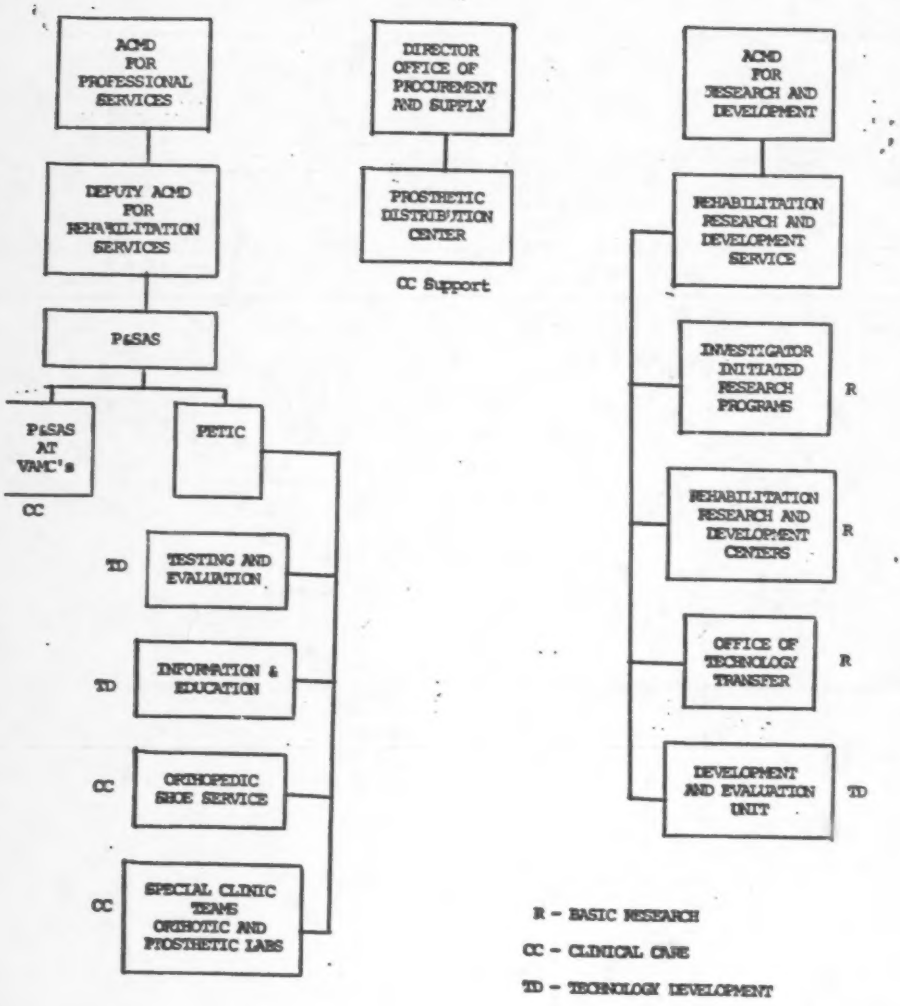
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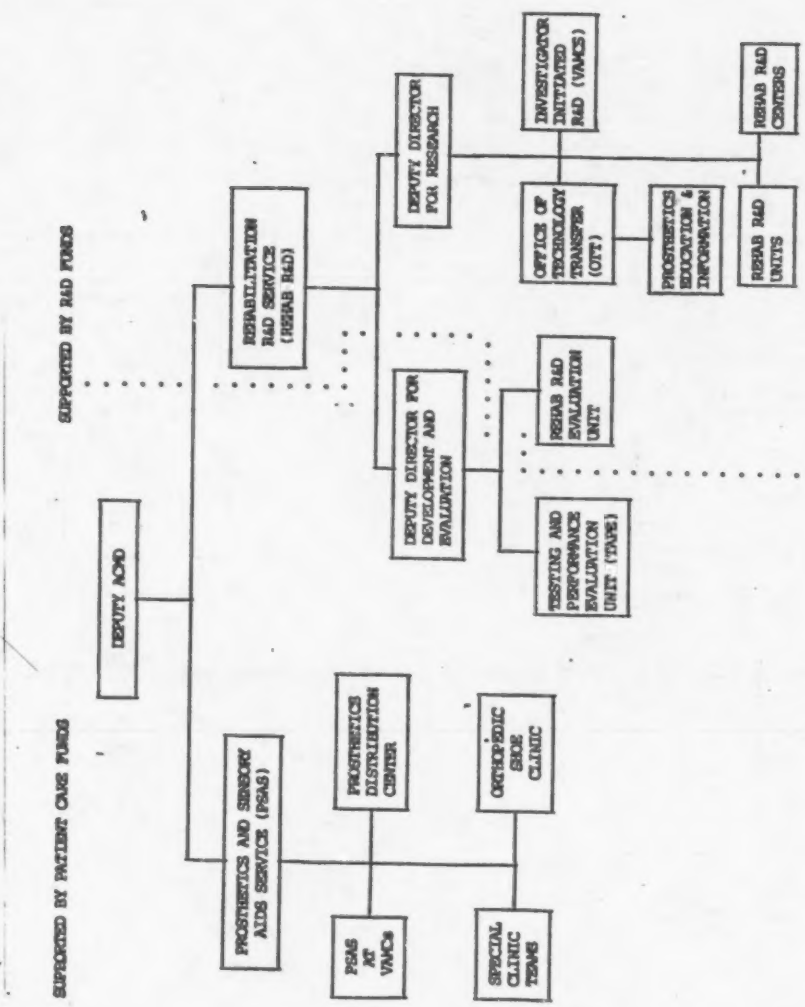
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REHAB R&D CENTERS

April 6, 1964

121

D. Earl Brown, Jr. M.D.
Associate Deputy
Chief Medical Director
VA Central Office (108)
Washington, D.C. 20420

Dear Earl:

You and Dr. Custis will shortly be making a decision on the Prosthetic Program reorganization. In regards to your request that I draft out my comments on the reorganization to you for Dr. Custis, I have an idea which I believe has merit.

Eliminate the Director of Technology Development Service. The two sections under that Service should either be divided between Dr. Giannini and me or both sections given completely to Dr. Giannini or to me.

I deduced from the vitriolic comments from one outside source that he thinks I have not effectively managed the 2 sections which is perhaps only those sections were put under the new Service. However, a review of the facts belie that perception. We have done a very good job of developing an evaluation procedure which is working.

In point of fact, other than the one critic (who I believe may be at heart an unhappy person) the other service organizations and internal VA operations as far as I know are satisfied with the evaluation procedures being worked out. The approximately 4 million dollars surplus at PETIC is there because I refused to continue the wasteful practice of evaluating projects, i.e. (1) without procedures to follow; (2) a lack of prescription guidelines; (3) a lack of evaluation protocols; (4) a lack of accountability of the equipment; (5) ignoring the respective Chiefs of Service in Rehabilitation Service and, (6) inadequate communication of the results of the evaluations.

It has taken time to correct these concerns because there was no existing system but, I have stuck by my guns and all of the above problems, I feel, are being addressed and will ultimately be a credit to DM&S.

I am asking for the chance to continue to carry out my duties in the area of commercial evaluations because it is starting to work and I would honestly like to have the satisfaction of seeing it to completion.

TO: Associate Deputy Chief Medical Director (10B)

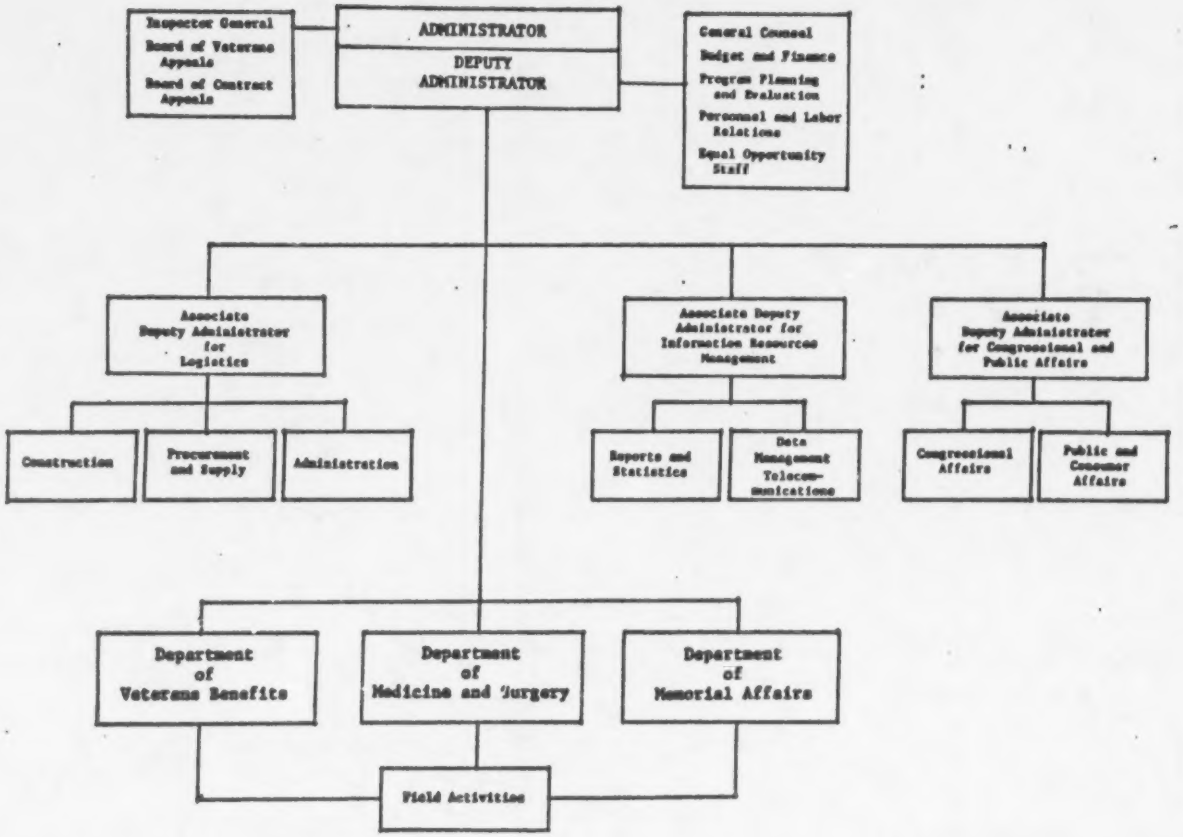
If there are strong feelings against my idea by the Administrator or you then I suggest that the Development Testing and Evaluation Section be put as a Section under Dr. Giannini's RR&D Center and that the Information and Education Service be made a Section under Dr. Giannini's Office of Technology Transfer. This would eliminate the use for a Director of Technology Development Service and would allow easier coordination between the two remaining Directors.

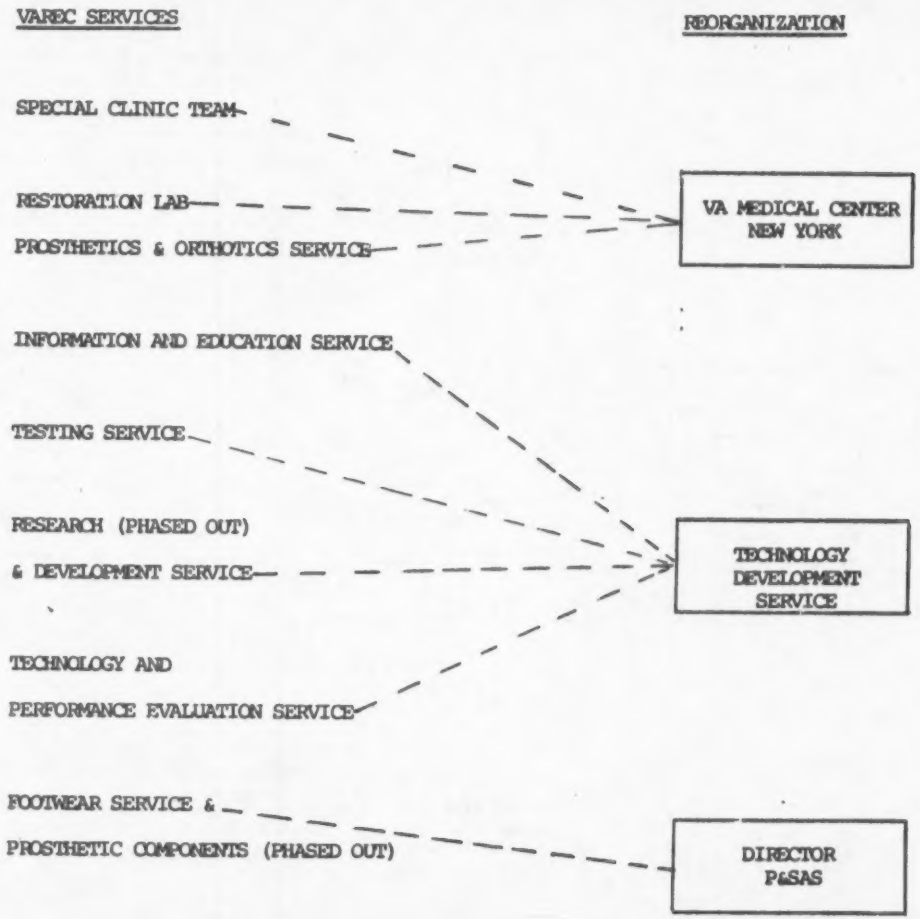
Thank you for reading this. I welcome the opportunity to point out some of the positive sides of the PETIC situation which you may not have been aware of.

FREDERICK DORNIS, JR.
Director, Prosthetic and
Sensory Aids Service

VETERANS ADMINISTRATION

APRIL 1983




VAREC SERVICES
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RESTORATION LAB
PROSTHETICS & ORTHOTICS SERVICE
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INFORMATION AND EDUCATION SERVICE
TESTING SERVICE
RESEARCH (PHASED OUT)
& DEVELOPMENT SERVICE
TECHNOLOGY DEVELOPMENT SERVICE
TECHNOLOGY AND
PERFORMANCE EVALUATION SERVICE
FOOTWEAR SERVICE &
PROSTHETIC COMPONENTS (PHASED OUT)
DIRECTOR P&SAS

STATEMENT BY ELLSWORTH L. SHARPE, IMMEDIATE PAST NATIONAL PRESIDENT OF THE BLINDED VETERANS ASSOCIATION

Chairman Edgar and members of the subcommittee, my name is Ellsworth L. Sharpe and I am the Immediate Past National President of the Blinded Veterans Association. I am very pleased to have the privilege to appear before this subcommittee today to represent the BVA and our National President, Mr. Thomas H. Miller, who could not be here today. I have had the opportunity to appear before this distinguished panel on previous occasions when I served as the BVA's National President. I am very happy to be here again today at this most important hearing schedule to consider the VA's medical research programs on prosthetics and rehabilitation.

I would like to commend Chairman Robert Edgar (D-PA) for scheduling this oversight hearing and for the efforts of this subcommittee to maintain and preserve the ability of the VA to respond to the medical and health care needs of America's veterans.

As you are probably aware, the Blinded Veterans Association was chartered by the U.S. Congress to represent the special needs of a targeted group of disabled veterans—blinded veterans. Ours is a specialized population with unique needs. Our programs promote self-sufficiency and we encourage blinded veterans to maximize their living skills. As for all disabled veterans, the VA is a vital tool to ensure the ability of blinded veterans to continue to live full and productive lives.

All disabled veterans have a vital interest in the VA's research efforts in the areas of prosthetics and rehabilitation. Disabled veterans rely on the VA to provide them with the means to maintain their lives. VA research, however, has not only been an asset to disabled veterans. Historically, the VA has been the leader in prosthetic research and rehabilitation. That image has been slightly tarnished in recent years because of budget cutbacks and efforts throughout all government to depress spending initiatives.

Although it is true that more money does not guarantee more capability or that there is a one to one ratio between dollars spent and benefits received, progress in prosthetic and rehabilitation research cannot go forward in a meaningful way without a substantial financial commitment.

VA Administrator Harry Walters has committed the agency to a path designed to recapture the VA's image as the innovator and the leader in prosthetics and rehabilitation. The BVA applauds his efforts in this regard.

Overall, the BVA is very concerned with the level of funding in the prosthetic and rehabilitative research programs. The BVA has already provided some information on these issues when our National President Thomas H. Miller presented the BVA's legislative program on March 28 in testimony before a joint hearing of the House and Senate Committees on Veterans Affairs.

A fact of modern life is that technology is rapidly advancing. What is new today is old tomorrow. Research has such great capability. However, it is the BVA's belief that enough is not being done now for blinded veterans. We believe that blinded veterans are not getting their share of the dollars from the VA's research budget.

In the area of research and development, as cited in our annual legislative statement, few projects specifically related to improving the lives of blinded veterans are approved and even fewer are funded.

Of the $150 million research and development budget, less than one percent is spent on research to help the blind and visually impaired. Although $4 million worth of research projects related to the blind were approved for R&D last year, they were not funded. Such projects are generally given low priority because blindness is not considered by researchers and bureaucrats to be a life-threatening situation. Part of the problem is a product of society's misunderstanding of blindness and the medical system's inability to deal with blindness. For many researchers and medical professionals, blind people represent failures of modern medicine and research. The tools needed to ensure rehabilitation and reinforce independent living skills are not considered to be medically oriented. Therefore, they receive low priority when funding decisions are made.

A similar problem exists relative to prosthetic research and providing aids and appliances to blinded veterans. As we have indicated before Congress in previous years, the total expenditure for aids and appliances for blinded veterans remains at a level approximating one percent of the VA's budget for sensory aids and prosthetics. In FY 83, for example, less than $800,000 was spent to purchase sensory aids and appliances for the blind. And even more signficantly, it takes the VA far too much times to provide an appliance or sensory aid to a blinded veteran after that aid or appliance is available on the market.

This situation is likely only to get worse in future years, especially as a result of the government's action this year to reduce funding which would have provided talking readers to blinded veterans. The VA proposed funding in FY 85 to provide fifty reading machines to blinded veterans at a total cost of $1.5 million. This funding was deleted by the Office of Management and Budget.

All the technology and all the research will not do veterans any good if the VA is not provided the financial resources to make the products of this technology and research available to the veterans themselves.

This major setback to the VA and to the BVA comes at a time when the needs of blinded veterans are being rebuffed in other areas as well. Not only has OMB cut funds for reading machines for blinded veterans, the VA, itself, has reneged on a commitment to provide additional Central Office funded Coordinators of Visual Impairment Service Teams for FY 84 and FY 85. And Senate action has jeopardized the establishment of a desperately needed blind rehabilitation program in Puerto Rico.

An additional point, the experience of the BVA has indicated that many of the chiefs of the various prosthetic services are unfamiliar with the needs of blinded veterans and, even more significantly, unaware of the availability of aids and appliances to meet these needs. We believe the VA should provide funding to train prosthetic chiefs and clerks so they will be sensitive to the specific needs of blinded veterans and aware of the technological advances which have been made. They should also be provided with periodic reviews so that they are always aware of the most recent innovations on the market.

It is also important to remember that the VA regulatory process is not keeping up with the rapid changes in technology. One of the single most fundamental advances for the blind and visually impaired is the talking personal computer. Yet, such an aid does not fit into existing regulations for issuance of prosthetics despite the fact that the personal computer can serve a vital rehabilitative function. Such regulation should be carefully scrutinized so they reflect the realities of modern living.

We can marvel together at the new innovations which modern technology brings us and we can speak together about the miracles of modern science and technology. As a blinded veteran, I am quite aware of the progress being made and I would invite members of this subcommittee and their staffs to attend the BVA convention trade show this August where aids and appliances for the blind and visually impaired are displayed and demonstrated.

Finally, I strongly encourage this subcommittee to consider the need for a comprehensive assessment in the form of an oversight hearing into medical and rehabilitative care and prosthetic and rehabilitation research relating to the needs of blinded veterans. The needs of blinded veterans deserve greater consideration. We strongly encourage this subcommittee to hold such hearings. Although we realize that time is at a premium during this session of Congress, we strongly encourage the members of this subcommittee to plan for such an oversight hearing early in the next Congress.

Again, I want to thank you very much for the opportunity to appear here today, and I will be pleased to answer any questions you might have.

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STATEMENT OF JOHN A. GRONVALL, M.D., DEPUTY CHIEF MEDICAL DIRECTOR, DEPARTMENT OF MEDICINE AND SURGERY, VETERANS' ADMINISTRATION CENTRAL OFFICE, WASHINGTON, DC

Mr. Chairman and members of the committee, my name is John A. Gronvall, M.D. I am the Deputy Chief Medical Director for the Department of Medicine and Surgery. I am pleased to have the opportunity to discuss the VA's Rehabilitation Research and Development (Rehab R&D) program, which, over the past 44 years, has provided the VA with innovative technology to benefit the disabled veteran.

The disabled veteran population consists of more than: 150,000 amputees, 48,000 of whom receive compensation or pension; 50,000 spinal cord injured, 22,000 of whom receive compensation or pension; 180,000 hearing impaired, 115,000 of whom receive compensation or pension; and 60,000 visually impaired or blind, 18,000 of whom receive compensation or pension. Although we are not now in a combat situation, the disabled population continues to grow as the veteran population ages. The VA also treats over 200 new cases of blindness each year. In FY 1983, the VA performed more than 3,000 amputations on eligible veterans because of peripheral vascular disease. The younger traumatically injured amputee has different rehabilitation needs than the older vascular amputee. This program addresses that broad spectrum rehabilitation.

The Rehab R&D Service mission is to improve the quality of life of impaired, disabled and handicapped veterans. This is accomplished by conducting a program of research, development and evaluation of devices, techniques and concepts of rehabilitation.

To better address these rehabilitation needs, the Rehab R&D Service has established three priority areas for new R&D. These areas, which represent the most prominent disabling conditions among veterans, are: prosthetics/amputation, spinal cord injury and sensory aids.

As of May 1, 1984 the $10.9 million FY 1984 Rehab R&D budget provided support for 97 Rehab R&D projects at 41 VAMCs having an average employment (FTEE) of 218. These projects included two Rehab R&D Centers (Palo Alto, CA and Hines, IL); three Rehab R&D Units (Decatur, GA, New York, NY and Washington, DC); and six Interagency Agreements (NASA, DoC, DoD).

The funding is subdivided among the following priority areas:

(1) Prosthetics/amputation.—FY 1984 funding: $4,300,000. Number of projects: 39. FTEE: 87.

Prosthetics/Amputation projects have the highest priority in the Rehab R&D program and programs have been initiated for:

The elderly—the development of new ultralight materials for artificial limbs;

The younger veteran—the development of more rugged devices to permit more vigorous recreational activities such as running, skiing and swimming;

The female veteran—the development of special contoured limbs and variable heel heights for high and low heeled shoes; and

All amputees—new R&D areas are being explored concerning the causes and alleviation of pain, pressure points and stump shrinkage, and improved external alignment for more comfort and ease of mobility. A major effort is planned to provide for increased comfort and more natural movement in amputees. This will be accomplished by developing a new generation of artificial limbs having sockets formed by a noncontact holographic technique which controls a computer-operated milling machine that shapes a socket to the exact dimensions of a patient's stump.

(2) Spinal cord injury.—FY 1984 funding: $3,300,000. Number of projects: 29. FTEE: 66.

Over 50,000 veterans have spinal cord injuries. Veterans so afflicted lose functional control of their body below the point of injury. A spinal cord injured individual with loss of leg movement is referred to as a paraplegic; the more severely injured patient loses functional control of both arms and legs, and is referred to as quadriplegic. These latter patients need attendant care to perform even the simplest functions. To improve the quality of life for high spinal cord injured veterans, Rehab R&D is developing voice-controlled robotic devices which can perform everyday tasks of living. These projects include voice activated robotic arms that can feed the patient and voice activated environmental controls to turn on and off equipment such as lights, TV, etc. To allow paraplegic veterans to stand and walk, a totally implantable computer driven system of functional electrical stimulation will be developed. Rehab R&D will conduct studies that lessen the effect of cord trauma and the resultant paralysis. There are also R&D studies to produce better wheelchairs for improved functional mobility.

(3) Sensory aids.—FY 1984 funding: $3,287,000. Number of projects: 28. FTEE: 65.

There are over 180,000 veterans with severe trauma-induced hearing impairment which is compounded by aging. Rehab R&D will support new studies for the hearing impaired including the development of computer-based hearing aids for the deaf that will remove repetitive background noise while improving sound direction. In addition, there are other device development projects for telecommunication aids, passive accoustical devices and devices to eliminate incessant ringing of the ears.

The service connected amputee has a higher incidence of stroke than the non-amputee veteran. To improve communication for stroke aphasia patients, Rehab R&D is conducting a multiple-hospital study of remote therapeutic modalities compared to those currently provided during out-patient visits.

An estimated 60,000 veterans have visual impairment. Of this number, 18,000 veterans receive VA compensation or pension. An increasing number of aging veterans are losing their vision. Rehab R&D will conduct studies to determine how blind people travel. New travel techniques will be evaluated and better methods to teach these techniques to handicapped individuals will be developed.

There are many outstanding efforts in this program as recognized by the numerous national and international awards and presentations by the investigators. Today I am especially pleased to present a cross section of R&D projects demonstrating the immediate clinical relevance of studies supported by the Rehab R&D Service. We have chosen projects that represent all three priority areas and address the diverse

needs of the disabled from routine activities of daily living to mobility and recreation. I believe this hearing is the appropriate forum for the Rehab R&D Service to receive recognition for the outstanding work they and all of their investigators are doing for disabled veterans.

That concludes my statement, Mr. Chairman. I will be pleased to answer any questions you or members of your committee may have.

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VETERANS' ADMINISTRATION,
DEPARTMENT OF MEDICINE AND SURGERY,
*Washington, DC, July 27, 1984.*

Hon. BOB EDGAR,
*Chairman, Subcommittee on Hospitals and Health Care, Committee on Veterans' Affairs, House of Representatives, Washington, DC.*

DEAR MR. CHAIRMAN: I am pleased to provide my views on the proposal advanced by the Disabled American Veterans to establish a position of Assistant Chief Medical Director for rehabilitation research, prosthetics, and related services.

The organizational strauctures proposed by the DAV would concentrate prosthetics and related programs in one organizational structure devoted exclusively to such programs. At the same time, it would place the central control point at a higher organizational level than at present. This offers the potential for a greater presence or visibility of these programs, and could facilitate programmatic change within the involved services. These potential advantages must, however, be weighed against the potential disadvantages.

The suggested organizational structure is unsound from the perspective of integration of care as it would isolate the involved programs. Organizational isolation tends to promote professional jealousies, struggles over turf, and rather rigid, often arbitrary, delineations of clinical privileges, duties, and responsibilities. While the proposal focuses on organization within Central Office, organizational alignments in the field generally follow those in Central Office. It is of particular concern to the Director, Prosthetic and Sensory Aids Service, that even now prosthetics field staff too often function in isolation rather than as interactive (and proactive) members of the health care delivery team. The need to correct this is important now, and will become more important as orthotic/prosthetic devices and procedures become more sophisticated and complex. Prosthetics staff will be progressively offering more service to patients with more complicated and serious problems, both medical and rehabilitative. This will demand increasing degrees of specialization and even subspecialization. It is vital to counterbalance this trend by integrating the individual specialists into an interactive interdisciplinary team if we are to treat people rather than parts of people. Thus, it is essential that prosthetics services and related development activities retain a close relatonship with the other professional services with which they interact. Organizational structures that isolate professional services will not help but would most likely add to the problem.

A related aspect of this problem is that such isolation can tend to sever intellectual ties, resulting in a narrowed vision. The inbreeding and lack of intellectual cross-fertilization that result can lead to lack of initiative and professional burnout. A good example is what had occurred at the Veterans Administration Rehabilitation Engineering Center in New York, New York. Because of a large degree of organizational autonomy, VAREC had severed its ties with the mainstream of clinical care and academic programs to the detriment of all.

The organizational changes proposed by the DAV are often of great value for focusing attention and expediting immediate change. They have the potential disadvantages, however, outlined above. In our opinion, the disadvantages outweight the advantages. We believe the proper focus can be given by placing the central control point in the office of a Deputy Assistant Chief Medical Director within Professional Services. This has the added value of maintaining organizational alignment with the related clinical services.

We have worked very closely with the DAV in structuring this reorganization which provides the Department, as well as the agency, a consolidated organization responsible for management and coordination of those activities related to prosthetics, including rehabilitation research and development. Organizationally consolidating these activities under the direction of a single manager within Professional Services will facilitate the delivery of high-quality care and at the same time provide a focal point for developlent of new and better devices and services. This is the goal of both the VA and the DAV. We feel strongly that the reorganization proposed by the Department will accomplish this common goal.

Thank you for the opportunity to express my views on this matter.

Sincerely,

JOHN A. GRONVALL, M.D.,
*Acting Chief Medical Director.*

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WRITTEN COMMITTEE QUESTIONS AND THEIR RESPONSE

CHAIRMAN EDGAR TO VETERANS' ADMINISTRATION

*Question 1.* During today's testimony of the Disabled American Veterans, the topic of the VA's Prosthetic Center in New York was discussed and the question was raised on exactly what is the function of that Center. This Subcommittee held oversight hearings on the effectiveness of prosthetic devices provided by the VA during November, 1981, at which time the New York facility was a topic of discussion based on an Inspector General's audit which detected many inconsistencies in management procedures. Would you please describe what changes have occurred at PETIC over the last two and one-half years? Additionally, what is the future direction of this facility in view of the relatively small number of veterans who have apparently been seen for prosthetic-related problems?

Answer. During the past two and one-half years the VA Prosthetic Center in New York has continued to operate under direction of temporary Acting Directors with close review and control by the Director, Prosthetic and Sensory Aids Service. Appointment of a Director is now in process. Although a reorganization for this activity is now being planned, no organizational changes have yet taken place. From a purely operational standpoint, production has decreased markedly due to the following reasons: The Prosthetic and Orthotic Service has provided an average of 15,000 services annually since 1982. This represents a 4-5% decrease from the previous years due to an inability to recruit qualified technicians in the New York area. The Restorations Clinic has provided an average of 900 services annually since 1982. There has been no decline in services by that unit. The Orthopedic Shoe Service has provided an average of 20,000 services annually since 1982 with no decline. The marked decline in production over the past two and one-half years has been in the number of testing and evaluation projects handled—200 annually as compared to 268 annually prior to 1982. This decline was due to the cancellation of outside contracts, pending reorganization. The future direction is to reassign Prosthetic/Orthotic Service and the Restoration Clinic to the VAMC New York. The Testing and Evaluation operation would be moved to the Washington, D.C. area under the direction of the Deputy ACMD for Prosthetic Services, Research, and Development as envisioned in the present reorganization plan currently under development. The Orthopedic Shoe Service will remain in New York City.

*Question 2.* During the testimony of the Disabled American Veterans, Mr. Gorman discussed what he perceived to be a need for a restructuring, or reorganization within DM&S to establish an Assistant Chief Medical Director who would have jurisdiction over Rehabilitation Research, Prosthetic and Sensory Aid Service, education and training programs as well as other related rehabilitative services. Please tell us the current status of the DAV's proposal regarding the Assistant Chief Medical Director. Has any firm decision been made regarding such a position?

Answer. The Administrator of Veterans Affairs has requested that the Prosthetics program be reorganized. The reorganization will include three components under a newly established position of Deputy ACMD for Prosthetic Services, Research, and Development. Those three components under the Deputy ACMD are: (1) Prosthetics and Sensory Aids Service, (2) Rehabilitation Research and Development Service; and (3) a Prosthetics Assessment and Information Center which would be located in the Washington, D.C. area. The Administrator has tentatively approved a draft version of the reorganization. A final package is being completed for the Administrator's review.

The Deputy ACMD for Rehabilitation Services will continue to function in that capacity and have responsibility for Audiology and Speech Pathology Service, Blind Rehabilitation Service, Rehabilitation Medicine Service, and Spinal Cord Injury Service.

The Education and Training portion will be handled by Academic Affairs under the Rehabilitation Education Program (REP). REP will furnish education and training needs to all Rehabilitation Services, including the newly formed office of Prosthetic Services, Research and Development.

*Question 3.* Has sufficient funding been made available for refinement of the Seattle foot project? If so, where do the funds originate? If funds have not been provided,

do you plan to commit future funds as would be necessary to perfect the foot?

Answer. Funds for the research and development of the Seattle foot project were from the Medical and Prosthetics appropriation. Additional funds were provided from the patient care appropriation to fabricate 500 Seattle Feet for a full scale clinical evaluation to begin later this summer.

*Question 4.* Have sufficient funds been devoted to the VA's Rehabilitation and Research and Development Service? If so, how do you explain the inability to fund meritor rehabilitation projects as compared with the vastly different medical research projects which have been funded?

Answer. There are whole areas of rehabilitation technology, as differentiated from health care technology, in which new R&D studies need to be mounted. These studies would explore how this rehabilitation technology could be applied to remedy loss of vigor, perception, and function such as decreased mobility and decreased sensory activity. Increased funding would enable expansion of the limited effort underway in some of these areas and permit the initiation of projects in new areas. There are presently over $3.0 million in merit-review approved but not funded rehabilitation R&D projects.

These presently unfunded projects are a result of increased interest in the VA R&D program. This increased interest has been seen in Medical, Research, Health Services R&D and Rehabilitation R&D. It has resulted in a larger number of meritorious, approved research projects than were originally anticipated when the Rehabilitation Research and Development budget for FY 1984 was submitted. Accordingly, these rehabilitation projects are intended to receive start-up funding in the FY 1985 allocation to the medical centers.

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STATEMENT OF LARRY J. LEIFER, PH.D, DIRECTOR, REHABILITATION RESEARCH AND DEVELOPMENT CENTER, VETERANS' ADMINISTRATION MEDICAL CENTER, PALO ALTO, CA, AND PROFESSOR, MECHANICAL ENGINEERING AND NEUROLOGY, STANFORD UNIVERSITY, STANFORD, CA

Mr. Chairman and members of the committee, my name is Larry J. Leifer, Ph.D. I am Director of the Rehabilitation Research and Development Center at the Veterans Administration Medical Center in Palo Alto, California; and Professor of Mechanical Engineering and Neurology at Stanford University, Stanford, California.

In responding to a 1977 VA request for proposals, I was a principal author of the program proposal that resulted in the establishment of a Rehabilitation Research and Development program in Palo Alto. The program is focused on bringing state-of-the-art engineering science and technology to the aid of disabled veterans (especially Vietnam veterans with severe disability). Preliminary funding and staffing for the center began in June 1978. Prior to that time I worked as a staff scientist for NASA, Ames Research Center, on physiological measures of human information processing. This line of investigation continued at the MIT Man-Vehicle Laboratory; and from 1973 to 1976 I was a Professor of Biomedical Systems Analysis at the Swiss Federal Institute of Technology in Zurich, Switzerland working on computer-aided clinical electrophysiology, postural stability analysis, electrical stimulation of hearing and oculo-motor systems analysis. In 1976, I joined the Stanford University Departments of Mechanical Engineering and Neurology. Shortly thereafter I began working in the field of rehabilitation engineering with physicians and staff at the Veterans Administration Medical Center in Palo Alto. Related professional activities include chairmanship of the ASME Technical Committee on Rehabilitation Engineering; chairmanship of the IEEE Technical Committee on Sensory Aids and Prosthetics; organization, speaking and writing contributions for the AAAS program on Science and Technology for the Handicapped; and extensive involvement in VA research and development project and program review.

Though our mandate within the Veterans Administration Research and Development program does not provide for direct "patient services" by our group, we have worked hard to involve disabled veterans and veteran service organizations in our choice and direction of projects. In most cases our research and development intitiatives have been a direct outcome of collaboration with local Veteran Administration Medical Center Services, including Spinal Cord Injury, Blind Rehabilitation, Physical Medicine and Rehabilitation, Orthopaedic Surgery, Neurology, and Reconstructive Plastic Surgery. We perform basic research needed to acquire knowledge about disability and the potential of technical solutions. We conduct applied research to render key concepts into practical devices. And, we work hard to assure that our efforts are known by others, especially the commercial sector of our society. This work is done by three operating units that correspond to the Veterans Administra-

tion's emphasis on Spinal Cord Injury, Prosthetics/Orthotics and Sensory Aids: 1. Nerve and Muscle Systems, 2. Orthopaedic Biomechanics, and 3. Human Machine Integration.

Affiliation between the Veterans Administration, the Stanford University School of Medicine and the Stanford School of Engineering has been a "cornerstone" for our entire endeavor. Extensive participation by faculty and students has contributed very importantly to our vigor and productivity. In the following paragraphs I would like to chronicle something of our work and philosophy.

I perceive our mandate to include two types of productivity. In the classical sense of biomedical research and development we are expected to produce "KNOWLEDGE". Our Progress Report (and bibliography) summarize this aspect of our work over the past four years and will receive no further attention in this testimony. Beyond information, and in a sense unique to rehabilitation, we are expected to produce ASSISTIVE DEVICES that will allow the veteran to live independently.

It is this latter category of productivity that deserves special attention today. The following four products (chosen from the many deliverables cited in the appendix) are available today for your examination:

1. ARROYA sit-ski for people with disabilities.—This device is now in use by hundreds of disabled veterans for recreational, therapeutic and competitive skiing. It is accessible to virtually an wheelchair user. Pilot research and development was done by Mr. Peter Axelson (initially as a Stanford student and subsequently as a Rehabilitation Research and Development engineer.) Mr. Axelson is a service-connected paraplegic veteran. I was the academic advisor on this project and supervised its refinement as a Rehabilitation Research and Development core project. The ARROYA project was first supported in October 1979 and produced commercially by Beneficial Designs, Inc. in October 1982.

2. Handbike for paraplegics and amputees.—This recumbent "bicycle" is accessible to most manual wheelchair users and, in a new "tandem" version will be accessible to any wheelchair user. It provides recreational, therapeutic and competitive biking. Pilot research and development was done by Mr. Douglas Schwandt and Ms. Candy Mintz as graduate students at Stanford (under the supervision of Professors Barkan and Leifer.) Susequent development under my supervision was done by Mr. Schwandt as a Rehabilitation Research and Development engineer. The Handbike has been tested by scores of veterans and is now available commercially (since October 1983) from Recreational Mobility, Inc.

3. Alexis omni-directional powered wheelchair.—This device is accessible to any wheelchair user and provides mobility in domestic and vocational environments not otherwise achievable. Pilot work was done by Rehabilitation Research and Development core staff as a spin-off of the Robotic Aid project. The mobility concept is based on a patent held by then-staff engineer Mr. William La, who was assisted by Mr. Timothy Koogle, and Mr. Robert Smith under my supervision. In development since the fall of 1980, we are demonstrating a second generation prototype that closely resembles a commercial version scheduled for public introduction in the first quarter of 1985 by International Texas Industries (INTEX), Inc. As has been the case with other product prototypes, the ALEXIS has been informally tested by a wide variety of veterans and may be of particular value to the elderly.

4. Robotic aid for the disabled and elderly.—This device is representative of a class of assistance devices intended to return, and/or augment, the manipulative function of veterans with severe physical limitations. It is special in that it promises to be a general purpose tool that could replace a wide variety of special appliances and be capable of working in a minimally structured environment. It has been the subject of a merit reviewed project since 1980 (Dr. Leifer is the Principal Investigator, Dr. Inder Perkash is the medical co-investigator.) It will be demonstrated by Machiel Van der Loos. It has also been a focal point of our effort to develop a methodology for early evaluation of research and development prototypes in clinical settings (K.G. Engelhardt). The system has been tested by over 90 individuals from the ages of 5 to 83 years. In a recent VA Nursing Home Care Unit pretesting, professional staff and elderly residents alike were overwhelmingly enthusiastic about the potential benefit of ROBOTIC AIDs to their lives and work. While this system is still very much in the research stage of development, it is of interest to know that it's development was given considerable attention at the recent "First International Personal Robotic Conference" in Albuquerque where the potential of robotics in health service delivery was highlighted by industry leaders such as Joseph Engelberger (president of Unimation, Inc.).

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions you may have.

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Veterans Administration Medical Center
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Additional information or reprints of individual reports contained herewithin are available upon request.

Produced by: David D. Dungan & Kevin C. McGill

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Dear Reader,

On behalf of the Rehabilitation Research and Development (RR&D) Center staff, I welcome your examination of our programs, our people, and our facilities. As you may note in more detail in the Center overview statement, this organization is dedicated to bring science and technology to bear on the problems faced by physically impaired veterans who are handicapped in the pursuit of living independence (socially and vocationally). This is a complex challenge and we have responded with a balanced program of research, design/development and evaluation. Though at this time we provide no patient-specific clinical services, we do include patients in the formulation of our objectives and in the day-to-day pursuit of those objectives. We also work closely with students and faculty at Stanford University. I hope that your reading of this report will be informative and that you will get to know us as individuals involved in a team effort to bring technology alive for us all.

Sincerely,

LARRY J. LEIFER, PH.D.
Director, Rehabilitation Research and Development Center

MARGUERITE T. HAYS, M.D.
Associate Chief of Staff/Research

FRANKLIN G. EBAUGH, JR., M.D.
Chief of Staff

JAMES C. DeNIRO
Medical Center Director

## Overview of RR&D Center Objectives

The Palo Alto RR&D Center has grown from a unique concept of Rehabilitation Engineering into a vigorously innovative group of individuals dedicated to building a new intellectual foundation for the use of engineering science and technology to aid disabled verterans and the disable community at large. Rehabilitation has emerged as this contry's number one medical cost category. Recognizing this and aware that the engineering profession could make a major contribution to the amelioration of handicaps incurred by physical disability, Dr. Thomas Newcomb recruited Dr. Vernon Nickel to establish an RR&D Service for the VA. The Palo Alto RR&D Center was announced in 1977.

Convinced that the VA could, and should, help build a basic engineering science foundation for Rehabilitation Engineering, they se out to build centers of excellence where the best of academic engineering could be brought into a collaborative relationship with the best of the VA's existing medical research community. To this end, the Rehabilitation Research and Development Center in Palo Alto is affiliated with the Stanford University Schools of Engineering and Medicine.

The Palo Alto RR&D Center is directed by Larry Leifer, Ph.D., and Professor of Mechanical Engineering at Stanford. It is housed in the modern functionality of a small landscape furnished office building on VA Medical Center grounds across the street from the Spinal Cord Injury Service (SCIS) and the Neurology Service. Physical Medicine and Rehabilitation (PR&R), the Western Blind Rehabilitation Center (WBRC) and the Geriatic Research Education and Clinical Center (GRECC) are a short wheelchair ride away. RR&D has a staff of 33 dedicated individuals who were largely recruited from outside of the existing rehabilitation community. The interaction with Stanford is continuous and occurs at many levels. It is one of the expressed objectives of the RR&D Center concept that engineering and medical students should be exposed to the exciting challenges that await them in a rehabilitation career. The Center's mandate can be briefly summarized in three goal statements:

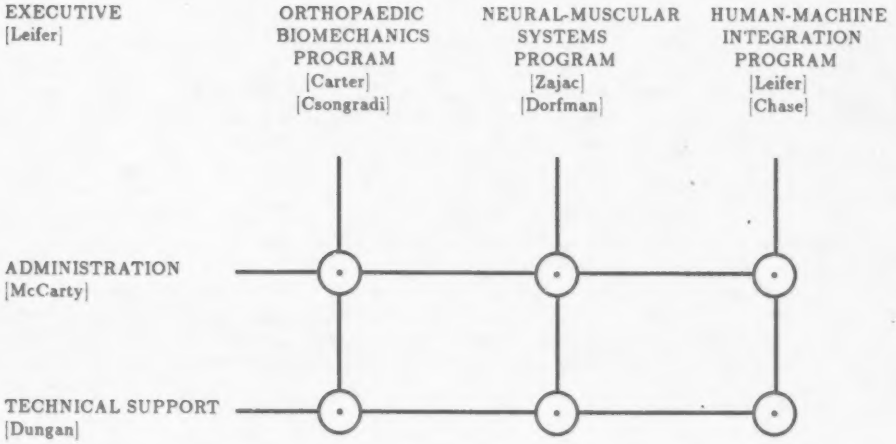
1. Perform basic research needed to understand physical disability and to define benefits that may be gained from the development of new devices and rehabilitation methods for the disabled. Emphasis is placed in the areas of:
    - Orthopaedic Biomechanics
    - Nerve and Muscle Systems
    - Man-Machine Integration
2. Design and develop manufacturable devices which advance the state-of-the-art in rehabilitation medicine and directly benefit disabled individuals:
    - Analytic modeling of disability and devices
    - Microelectronics and smart electromechanical systems
    - Comprehensive product design which deals with the physical, intellectual and emotional needs of the user
3. Assure the availability of new methods and devices through an active program in the following areas:
    - Evaluate new devices and methods in clinical and outpatient environments

- Train physicians, therapists and patients in the use and maintenance of rehabilitative devices
- License production of new rehabilitative devices
- Promote understanding and widespread adoption of worthy new devices and methodology through publications and presentations

Research and development activity in the Center is divided into three program areas. Each program is led by a senior engineer who holds a regular faculty appointment in the Stanford School of Engineering, and a physician, who holds a regular faculty appointment in the Stanford School of Medicine. Thus interaction between the VA and the Stanford School of Engineering closely approximates the VA's longstanding and successful Medical School Affiliation. Each program area is unique in its approach to excellence. Each is built upon the existing track record of an experienced researcher who has turned his/her professional energies to the challenge of making rehabilitation a premier academic discipline.

Center resources are focused on bringing top quality people into the rehabilitation community where they form investigative partnerships with a wide variety of research physicians within the VA Medical Center to work on research projects. In this way the RR&D Center augments an already strong VA research community rather than attempting to build a completely autonomous and possibly insular discipline. To further assure that engineering, medical and user objectives remain harmonious, all RR&D projects are subject to a variety of peer review processes. A review of program and project specific activity in section [6] will illustrate the pursuit of these objectives.

**RR&D Center Internal Organization**




Advisory Committee:

Larry Leifer, Ph.D., Director
Dennis Carter Ph.D., Orthopaedic Biomechanics Program Director
John Csongradi, M.D., Orthopaedic Biomechanics Program Medical Director
Felix Zajac, Ph.D., Neural and Muscular Systems Program Director
Leslie Dorfman, M.D., Neural and Muscular Systems Program Medical Director
Larry Leifer, Ph.D., Human-Machine Integration Program Director
Robert Chase, M.D., Human-Machine Integration Program Medical Director
Patricia McCarty, M.A., Administrative Group Supervisor
David Dungan, Technical Support Group Supervisor

## Current Staff

(January, 1984)

**Executive:**

| | |
|---|---|
| Leifer, Larry J., Ph.D., | Director, RR&D Center<br>Director Human-Machine Integration Program<br>Assoc. Professor, Mechanical Engineering, Stanford |

**Administrative Group:**

| | |
|---|---|
| McCarty, Patricia, M.A., | Adminstrative Group Supervisor<br>Staff Assistant |
| DeMaio, Rose M., | Editorial Assistant |
| Montague, Aldean, | Secretary |

**Human-Machine Integration Program:**

| | |
|---|---|
| Leifer, Larry J., Ph.D., | Director, RR&D Center<br>Director Human-Machine Integration Program<br>Assoc. Professor, Mechanical Engineering, Stanford |
| Chase, Robert A., M.D., | Medical Director, Human-Machine Integeration Program<br>Professor, Surgery Department, Stanford |
| Awad, Roger E., M.S., | Equipment Specialist |
| Axelson, Peter W., M.S., | Biomedical Engineer |
| Buckley, Charles, M.S., | Biomedical Engineer |
| Curran, Allen R., M.S., | Biomedical Engineer |
| Curtis, Gayle E., M.S., | Biomedical Engineer |
| Engelhardt, K.G., B.A., | Research Health Scientist |
| Elsasser, Urs, Ph.D., | Research Associate |
| Goodrich, Gregory, Ph.D., | Research Psychologist |
| Hennies, Walter D., M.S., | Biomedical Engineer |
| Hennessey, Wade | Computer Clerk |
| Holloway, Karen, B.S., | Biomedical Engineer |
| Ives, Douglas, M.S., | Biomedical Engineer |
| Jaffe, David L., M.S., | Biomedical Engineer |
| Jameson, John, M.S., | Biomedical Engineer |
| Lakin, Fred H., M.F.A., | Research Health Scientist |
| Michalowksi, Stefan, Ph.D., | Research Associate |
| Perkash, Inder, M.D., | Chief, Spinal Cord Injury Center |
| Sabelman, Eric E., Ph.D., | Biomedical Engineer (consultant) |
| Sacks, Alvin, Ph.D., | Biomedical Engineer (consultant) |
| Schwandt, Douglas, M.S., | Biomedical Engineer |
| Scurlock, Charles, | Industrial Liaison (consultant) |
| Shindell, Steven, M. Ph.D., | Research Psychologist |
| Smith, Robert E., M.S., | Biomedical Engineer |
| Steele, Richard, Ph.D., | Research Health Scientist |
| Swanson, Brian, B.S., | Biological Aide |
| Tang, John, M.S., | Biomedical Engineer |
| Van der Loos, Machiel, Dipl.Ing., | R&D Engineer |
| Waleska, John, M.S., | Biomedical Engineer |
| Wampler, Charles, M.S., | Biomedical Engineer |
| Wicke, Roger, Ph.D., | Biomedical Engineer |

**Neural and Muscular Systems Program:**

| | |
|---|---|
| Zajac, Felix E., Ph.D., | Program Director, Neural and Muscular Systems<br>Professor (Research), Mechanical Engineering, Stanford |
| Dorfman, Leslie J., M.D., | Medical Director, Neural and Muscular Systems Program<br>Assoc. Professor, Department of Neurology, Stanford |
| Abraham, Gordon, M.S., | Biomedical Engineer |
| Boylls, C. Curtis, Ph.D., | Biomedical Engineer |
| Cohen, Lisa, B.S., | Research Health Scientist |
| Dwan, William, B.S., | Biomedical Engineer |
| Gaines, Ronald, M.D., | Physician, Spinal Cord Injury Center |
| Go, Mae Seam, B.S., | Biological Aide |
| Hentz, V. Rodney, M.D., | Chief, Plastic & Reconstructive Surgery Division<br>Associate Professor, Surgery, Stanford |
| McGill, Kevin, M.S., | Biomedical Engineer |
| Onyski, Jean, B.S., | Biomedical Engineer |
| Perkash, Inder, M.D., | Chief, Spinal Cord Injury Center |
| Tappel, James, B.S., | Biomedical Engineer |
| Zomlefer, Michael, Ph.D., | Biomedical Engineer |

**Orthopaedic Biomechanics Program:**

| | |
|---|---|
| Carter, Dennis R., Ph.D., | Program Director, Orthopaedic Biomechanics<br>Assoc. Professor (Research), Mechanical Engineering, Stanford |
| Csongradi, John J., M.S., M.D., | Medical Director, Orthopaedic Biomechanics Program;<br>Chief, Orthopaedic Surgery, VA<br>Assistant Professor, Surgery, Stanford |
| Caler, William, B.S., | Research Assistant |
| Gies, Alice, M.S., | Biomedical Engineer |
| Kennedy, John, M.S., | Biomedical Engineer |
| Orr, Tracy, M.S., | Biomedical Engineer |
| Rapperport, Daniel, M.S., | Biomedical Engineer |
| Selker, Frank, B.S., | Research Health Scientist |
| Squire, Bernadette, B.S., | Research Assistant |
| Van Ingen, Caroline, B.S., | Biomedical Engineer |
| Vasu, Ramiah, M.S., | Research Assistant |
| Whalen, Robert, M.S., | Biomedical Engineer |

**Technical Support Group:**

| | |
|---|---|
| Dungan, David, | Technical Support Group Supervisor<br>Computer Systems Analyst |
| Anderson, James H., | Model Maker |
| Bishop, Earl H., B.S., | Biological Lab Technician |
| Chang, Melva S.E., B.S., | Biomedical Engineer |

## Collaborative Interactions

Individual members of the RR&D Center are currently collaborating with a wide variety of other organizations. Though some of the interactions are formalized by contracts and co-authorships, some important transactions take place on an informal one–on–one basis. Individual initiative is encouraged and supported. Project abstracts in section [6] contain additional detail.

VA MEDICAL CENTER
- Geriatric Research and Education Center
- Neurology
- Orthopaedic Surgery
- Physical Medicine and Rehabilitation
- Plastic Surgery
- Spinal Cord Injury Center
- Western Blind Rehabilitation Center

STANFORD UNIVERSITY
- Biology Department
- Boy's Town Center for Youth Development
- Computer Science Department
- Communication Department
- Electrical Engineering Department
- Institute for Mathematical Studies in the Social Sciences
- Linguistics Department
- Mechanical Engineering Department
- Neurology Department
- Psychology Department
- Sociology Department
- Speech and Hearing Department
- Structural Biology Department
- Surgery Department
  - Orthopaedic
  - Plastic and Reconstructive
  - General

BAY AREA INSTITUTIONS
- Center for Independent Living, Berkeley
- Fairchild Laboratory for Artificial Intelligence Research (FLAIR),
  Fairchild Laboratories, a Division of Schlumberger Incorporated
- NASA, Ames Research Center
  - Man-Machine Integration Branch
  - Project Technology Branch
  - Research Facilities and Instrumentation Division
- Palo Alto Foundation for the Handicapped
- Palo Alto Senior Citizens Foundation
- Rehabilitation Engineering Center, Children's Hospital at Stanford
- Senior Center of Palo Alto
- Senior Day Health Care Program
- Sensory Aids Foundation

Smith-Kettlewell Institute of Visual Sciences
Spinal Cord Injury Center, Santa Clara Valley Medical Center
Telesensory Systems Incorporated
Unimation Incorporated
University of California, Berkeley
    Mechanical Engineering Department
    School of Optometry
University of Santa Clara
    Electrical Engineering and Computer Science Department

OTHER INSTITUTIONS
American Foundation for the Blind, New York
Community Resources for Independence, Santa Rosa, CA
Electrical Engineering Department, University of Maryland
LeHigh University, Dr. Walsh
Miami Jewish Home for the Aged, Stein Research Center
Paralyzed Veterans of America
Physical Medicine and Rehabilitation, University of California, Davis
Syracuse University, NY
American Association of Retired Persons, D.C.

## Orthopaedic Biomechanics Program Overview

The Orthopaedic Biomechanics Program conducts research and development with an emphasis ranging from basic research to applied, implant design. We feel that better patient care and rehabilitation must come from strategies which are founded on a knowledge of fundamental physiological and biomechanical principles. Some of the basic research conducted includes investigations of: the mechanical properties of bone, bone fracture healing and remodelling, and the relationships between *in vivo* bone stress and bone physiology.

Knowledge gained in these studies is applied by our group and other researchers for patient diagnosis and prognosis and in providing design criteria for orthopaedic implants. For example, basic research has developed mathematic relationships for cancellous bone strength and stiffness as a function of bone apparent density. These relationships are now being used as guidelines in developing new CT scan techniques for assessing bone strength in osteoporotic patients. The relationships are also used in computer simulations of total joint replacements by ourselves and other researchers who are evaluating various design parameters.

In our applied work, we are studying orthopaedic implants such as total joint replacements, fracture plates, and spinal stabilization techniques. Our philosophy is generally to investigate and evaluate implant designs from a generic perspective. That is, we try to identify design parameters which are distinctive and evaluate various design options. The emphasis is not necessarily to develop and champion a specific device but rather to provide a framework in which prosthesis design should proceed. The dissemination of the results of this type of work influences the way in which others in the orthopaedic community and industry approach implant design and, ultimately, patient treatment and rehabilitation.



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# ANALYSIS OF FEMORAL EPIPHYSEAL REPLACEMENT DESIGNS

DENNIS R. CARTER, Ph.D. — Principal investigator, VA
DAVID P. FYHRIE, M.S. — Biomedical engineer, VA

**PROBLEM:** It was hoped that surface replacement arthroplasty would be a reconstruction procedure especially suitable for younger patients. The failure rates of many types of cemented surface replacement components have been disappointing.

**SIGNIFICANCE:** The primary goal of this project is the evaluation of the hypothesis of epiphyseal replacement and design of a prototype implant using three dimensional finite element analyses which model non-ideal interfaces.

A secondary goal of this study is evaluation of the two dimensional analysis procedures which are commonly used to approximate the stresses in intrinsically three dimensional problems. With proper guidelines these two dimensional methods may become reliable tools for the design of prosthetic devices due to their ease of use and low cost relative to the more accurate three dimensional analysis procedures.

**BACKGROUND:** A new epiphyseal replacement design attempts to reproduce the natural stress patterns by replacing only the bone superior to the epiphyseal scar. The hypothesis is that since the epiphyseal (growth) plate in an immature person is composed of cartilage, which has small shear and tensile moduli, that the tractions across the plate must be principally compressive and normal to the plate.

Results of idealized finite element models of the natural femur and epiphyseal replacement tend to support this hypothesis.

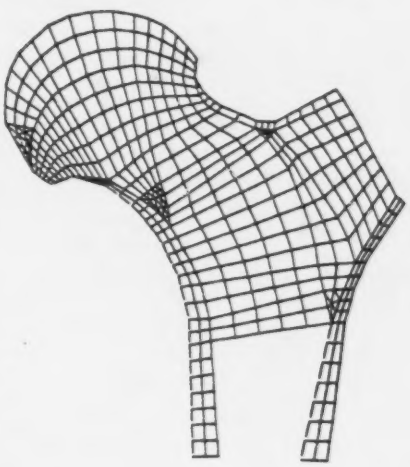

Figure 1. Proximal Model of Femur, Finite Element Mesh.

**HYPOTHESIS:** Numerical and experimental analyses of the designs have led to the hypothesis that clinical failure is due to drastic changes in the natural transmission of forces through the femoral head after insertion of the surface replacement.

**APPROACH:** Idealized analyses assume that the bone/prosthesis interface is not a slip surface. In general, it is not reasonable to assume that the prosthesis will have this perfect adhesion at the interface. Clinical studies have shown that a thin layer of fibrous tissue tends to form at the cement/bone interface for cemented prostheses. This layer has low shear and tensile moduli, leading to a nearly frictionless interface. For bony ingrowth prostheses this layer may form as well if the ingrowth does not proceed properly. In addition, the interface may slip immediately after surgery since the prosthesis is not stable until the ingrowth occurs.

**STATUS:** Preliminary two dimensional studies with slip surfaces have shown that positional stability of a bony ingrowth prosthesis may be difficult to achieve without special provision for attachment immediately post-surgery. Whether these indications of instability will occur in three dimensional analyses as well will be determined in future studies.

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Project support: NIH Grant AM32378
RR&D base resources and funds
October 1982 through October 1984

# RADIOLOGICAL DETERMINATION OF BONE STRENGTH


| | |
|---|---|
| DENNIS R. CARTER, Ph.D. | Principal investigator, VA and Stanford |
| GRAHAM SUMMERS, M.D. | Co-investigator, Stanford |
| DAVID SARTORIS, M.D. | Co-investigator, Stanford |
| ALICE A. GIES, M.S. | Co-investigator, VA |


**PROBLEM:** Noninvasive quantification of bone strength would serve as a significant resource to the rehabilitation community in planning rehabilitation strategy. To effectively serve as a body structural component bone must have adequate strength. With emerging imaging technologies, the quantitative, noninvasive evaluation of bone structural adequacy is becoming a clinical possibility. Dual energy single projection radiography and computed tomography are among tools allowing evaluation of bone in ways that have only begun to be appreciated.

**SIGNIFICANCE:** Quantitative use of image data for prediction of bone properties is still in its infancy. Exciting breakthroughs can be anticipated. These should unlock many possibilities both in clinical evaluation of bone for direct help to patients and in more general research on the physiological responses of bone in vivo. The ability to analyze bone as a structure noninvasively should result in dramatic increases in the pool of knowledge on bone physiology and pathology hence improving the quality of life for those afflicted with bone disorders.

**BACKGROUND:** A prototype facility for dual energy single projection radiography has been developed at Stanford. The dual energy technique allows subtracting from the image components possessing a chosen average atomic weight. This capability has myriad of potential applications. In particular our hope is to exploit this capability to improve physicians ability to assess bone strength. Osteoporosis resulting in hip fracture has been chosen as a first subject for study as a basis for methodology development. CT scan and materials testing are among other facilities available to our interdisciplinary group to aid our development of innovative, noninvasive techniques for structural assessment of bone.

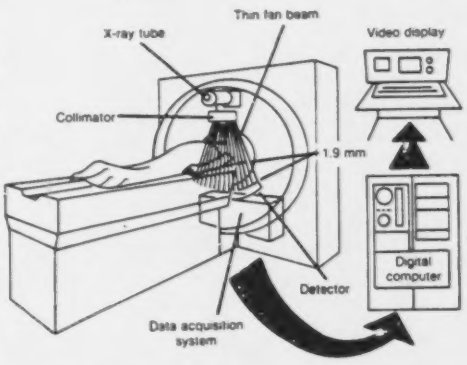


Figure 1. Dual Energy Scanned Projection Radiography. The fan beam is pulsed alternately at high and low levels as the patient advances through the scanner. Each pulse forms one line of the image which is constructed by the digital processor.

**HYPOTHESIS:** Digital radiographic techniques provide a wealth of X-ray absorption data which can be correlated with bone density and thickness. These, in turn, can be correlated with experimental bone strength. We hypothesize that the relationship between bone strength and image intensity developed experimentally will provide predictive information regarding potential clinical fractures.

**APPROACH:** Several dozen femur specimens and several dozen volunteer patients will be subjected to dual energy single projection scans. Several methods for judging the strength of

the femoral neck will be employed. These include: judgment of strength directly from transmitted intensity as a density proxy, prediction of strength from bone sectional properties computed from transmitted intensities, and utilization of a ratio image relating bone mineral–like to soft tissue–like components in the bone. Materials testing of the experimental femurs will be undertaken to confirm the validity of the methods developed.

**STATUS:** Scans of the experimental femurs and most of the patients are complete. One phase of materials testing of the experimental femurs, experimental fracture induction, is also complete. A second phase of materials testing, determination of femoral neck densities and ash weights, remains to be done. Other objectives for the remainder of the year include recalibration of the scanner with respect to bone, continued data analysis using the methods developed, and evaluation of the predictive performance of the various methodologies employed.

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Project support: RR&D base resources and funds
June 1983 to July 1984

# STRESS ANALYSIS FOR THE NORMAL AND PROSTHETIC SHOULDER

DENNIS R. CARTER, Ph.D. — Principal investigator, VA and Stanford
TRACY E. ORR, M.E. — Co-principal investigator, VA and Stanford

**PROBLEM:** For patients with arthritis and other crippling diseases, the total joint replacement has become a standard procedure to relieve pain and increase mobility. Bone grows in response to the mechanical loading applied. Therefore, engineering has become increasingly important in determining the changes in stresses due to the implantation of a prosthesis. Once the stresses of the anatomic joint have been determined, these stresses can be compared to those of an prosthetic bone. Although the knee and hip joint have been analyzed extensively, the shoulder joint has so far been neglected in any stress analysis. The problem is to model mathematically the humerus and glenoid of the shoulder joint, and to apply anatomic boundary and loading conditions to determine stress distributions. The concepts that will produce a prosthesis which will distribute the stresses similar to the normal humerus and glenoid will be determined.

**SIGNIFICANCE:** The objective of this study is to more fully understand the biomechanics of the shoulder joint and to analyze some of the existing shoulder prostheses. By improving the design of the shoulder replacement, patients will again be able to perform simple daily tasks such as brushing the hair or removing items from a shelf. By determining the underlying concepts behind an optimum design, the shoulder replacement will last longer and remove the need for revisions.

**BACKGROUND:** Finite element analyses have been performed on the hip and knee joint by the Biomechanics Group. The Finite Element Method allows the bone to be modelled mathematically and enables several prosthetic designs to be analyzed using the same boundary and loading conditions. Stress distributions obtained from existing prostheses are compared to the anatomic model. Similar techniques are used for the shoulder joint.

**HYPOTHESIS:** It is believed that the optimum prosthetic design is one which will distribute stresses similarly to that of the anatomic bone. It is also hypothesized that only principal stresses should be transmitted across the prosthesis/bone interface.

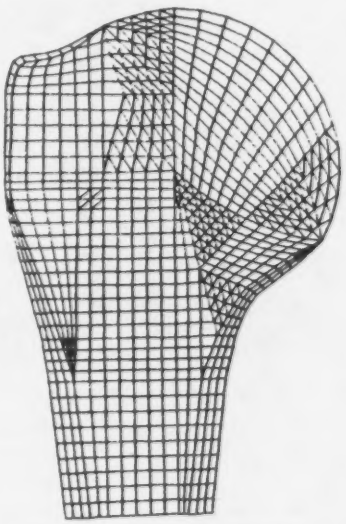

Figure 1. Finite Element Mesh of Humerus.

**APPROACH:** Cadaver humerus and scapula are sliced in order to obtain the geometry and material properties. A finite element mesh is generated and anatomic loading and boundary conditions are applied. The results of the anatomic humerus and glenoid are compared with a number of different prosthetic designs. Several types of finite element models are going to be employed: plane strain, equivalent thickness, axi-symmetric, non-

linear contact, and three dimenional analysis. At least six different prosthetic designs are analyzed using three loading cases.

**STATUS:** Finite element models of two types have been generated to analyze the humerus: a plane strain model and an equivalent thickness model. The principal stresses and the von Mises' stress contours of the normal humerus have been determined for three different loading conditions. Six different prosthetic designs have been analyzed and compared with the normal humerus. The next step is to examine the stresses across the interface. The glenoid will be analyzed next. Then the other types of analysis will be developed.

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Project support: RR&D base resources and funds
September 1983 to October 1984

# ANALYSIS OF ACETABULAR COMPONENT DESIGNS

DENNIS R. CARTER, Ph.D., Principal investigator, VA and Stanford
DANIEL RAPPERPORT, M.S. Biomedical engineer

**PROBLEM:** Failure of fixation of the acetabular component in a total hip replacement is found with increasing frequency as longer patient follow-ups are obtained. A component which eliminates these deficiencies is needed. This research effort represents the most ambitious attempt to analyze the acetabular component and surrounding bone. A more rigorous analysis is required in order to confidently evaluate different cup designs. Our goal is to design a prosthesis with an improved expected lifetime.

**BACKGROUND:** The two principal modes of acetabular component failure are cup loosening and cup migration through the supporting bone. Poor bonding between component and adjacent bone is responsible for cup loosening. Abnormally high local stresses cause migration either through direct trabecular bone fracture or detrimental bone remodelling.

**HYPOTHESIS:** Better acetabular component fixation will be obtained by transfering stresses to the cortical bone of the ilium, ischium and pubis adjacent to the actabulum.

**APPROACH:** To obtain better acetabular component fixation we have designed the component to capture the cortical bone immediately adjacent to the acetabulum. Detailed knowledge of the stess fields around the acetabulum is essential for understanding the mechanical behavior of the normal acetabulum and the acetabulum after total hip replacement. A complete three dimensional finite element analysis with contact elements has been initiated. Element material properties have been calculated from radial slices of a cadaver hip. The addition of contact elements should more accurately model the transmission of load across the joint.

**STATUS:** Preliminary contact finite element stress analysis of the natural hip has been conducted.

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Project support: NIH Grant 32378
RR&D base resources and funds

DENNIS CARTER, Ph.D. — Principal investigator, V.A. and Stanford

FRANK SELKER, B.A. — Co-investigator, V.A.

**PROBLEM:** Allometry is the study of scaling principles that apply across across different sizes of structures. Existing theories which deal with the structure of animal skeletons are only partially successful. In particular, there is no satisfactory model to relate bone loading, density, and material properties across the range of animal sizes. It is the goal of the allometry project to formulate such a model.

**SIGNIFICANCE:** To the extent that current models are unsuccesful, our understanding of skeletal architecture will remain incomplete. A successful model will elucidate critical factors which determine the size and shape of bones. This basic knowledge may be extremely useful in understanding and treating bone disorders.

**BACKGROUND:** Theories pertaining to animal scaling have been debated for many years, but only since the early 1970's has attention turned towards bones and skeletons in a detailed manner. Several models of bone allometry have been proposed - most prominently: geometric (or proportional) scaling, and elastic scaling (related to bone's resistance to buckling). Available data does not consistently support any existing model; important anomolies have yet to be accounted for.

**HYPOTHESIS:** Organisms have tended to optimize the mechanical properties of their skeletons. The resulting bone dimensions can be explained using a few of the most important cost/benefit trade-offs and design constraints.

**APPROACH:** The approach is a combination of analytical and empirical: Mathematical models which which make biological and structural sense will be formulated, and collected from the literature. To discriminate between the competing theories, data will be collected from specimens and the literature. This will allow construction of a model which provides both credible explanations, and describes the data.

**STATUS:** Geometric data is being collected on bones borrowed from the California Academy of Sciences, San Francisco. With the aid of computer-aided tomography films, and a digitizing tablet, bone geometry is being entered into a computer for analysis. Prominent theories proposed in the literature have been examined, and call for comparison with the above data.

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Project support: RR&D base resources and funding
September 1982 to October 1984

# ANALYSIS OF A NEW HIP PROSTHESIS

DENNIS R. CARTER, Ph.D. — Principal investigator, VA and Stanford
CAROLINE VAN INGEN, M.S. — Candidate, Stanford

**PROBLEM:** The expected lifetime for total hip implants is approximately ten years. Failure results from gradual component loosening or component induced stress shielding with subsequent loss of critical bone mass. An implant design which extends this lifetime is needed. The applied loads on the hip are transferred through the stiffer implant to the distal end of the component. The stress shielding that results in the proximal region induces bone atrophy and component loosening. A prosthesis should transmit loads without altering the stress field of adjacent bone.

**SIGNIFICANCE:** The results from this analysis should yield a femoral component design which better mimics the loading behavior of the intact joint. We anticipate that this will result in a significant increase in the expected lifetime for hip implants.

**BACKGROUND:** Prostheses cemented in place give immediate fixation and stabilty, but the interface breaks down and leads to component loosening. Sintered porous coated implants eventually develop excellent fixation, but with existing designs the efficient load transmission across the bony ingrowth interface alters the local stress field . Detrimental remodelling has been a major contributor to porous coated implant failure.

**HYPOTHESIS:** Component loosening can be discouraged by inducing stresses in the proximal area to prevent bone atrophy. Attaching a collar to the component and selectively applying a porous coat to the implant surface will transfer the load to the immediate area. If the collar is formed so that its surface is normal to the applied loads, then only principal compressive stresses will be transmitted across the collar.

**APPROACH:** We have approached the problem with a two dimensional finite element model of the entire component made up of 3- and 4-sided elements. We are modelling and analyzing three different prosthesis collar configurations: 1) flat disk, 2) cone with an angle of 30 degrees from its upper surface, and 3) cap with an angle of 30 degrees from the bottom surface. Since our interest lies primarily in the region around the neck and collar we will develop a finite element model only of the proximal portion of the component in the femur. It will be composed of both 3- and 4-sided elements. Contact elements will be used if a complete three dimensional analysis is required.

**STATUS:** A finite element model of the proximal portion of the component in the femur has been developed. An analysis of the neck and collar region indicates that a three dimensional model might be more appropriate. Photoelasticity is also another alternative that we may use to analyze the hip prosthesis.

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Project support: Base resources and funds
August 1983 to August 1984

# EXTERNAL AND INTERNAL STABILIZATION OF THE DISRUPTED CERVICAL SPINE


| | |
|---|---|
| JOHN CSONGRADI, M.D. | Principal investigator, VA and Stanford |
| DONALD NAGEL, M.D. | Co-investigator, Stanford |
| ROBERT WHALEN, M.S. | Co-investigator, VA |
| FRANK SELKER, B.S. | M.S. candidate, Research Assistant |


**PROBLEM:** The cervical spine is difficult to stabilize following fracture dislocation. The current techniques for stabilizing the fracture dislocated cervical spine include halo devices and bone grafting. The halo devices appear effective, but they are cumbersome. The various grafting techniques do not provide stability throughout the healing process and often fail, even in the presence of protective collars. A surgically implanted stabilizing instrument would be an effective treatment in many cases.

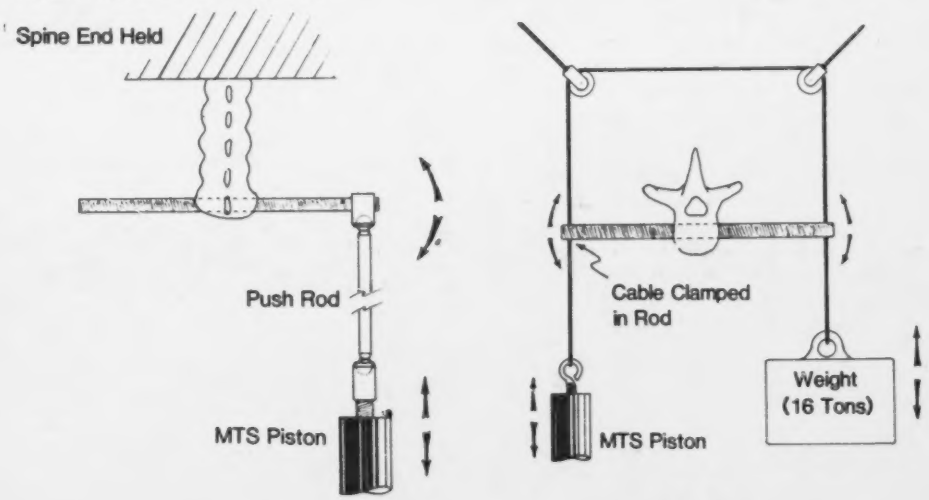


Figure 1. Loading spine in lateral bending (left) and loading in axial rotation (right).

**SIGNIFICANCE:** This program will provide clinicians with an effective surgically implantable stabilization instrument. In addition, the stability data from various methods will provide the clinician with quantitative data to help him/her select the best method for each patient. This improved clinical approach will result in fewer stability related complications, lower costs, and improved patient comfort.

**BACKGROUND:** Studies of the motion of the entire cervical spine in the presence of halo devices have produced widely varying results. While grafting and wiring techniques have produced acceptable results in cadaver studies, these methods sometimes fail to provide stability long enough for fusion to occur. The use of wires and PMMA produce immediate stability, but infection rates

have been high.

**HYPOTHESIS:** Harrington rods have not been modified to stabilize the cervical spine and it appears difficult to do so. However, the segmentally wired Luque rods are easily reduced in size and can be shaped for surgical application. Therefore, this technique or modifications of it should produce an acceptable, surgically implantable, stabilizing instrument for the dislocated cervical spine.

**APPROACH:** We will use the motion transducer developed for our lumbo-dorsal studies to measure relative motion of cervical vertebrae. We will measure the relative rigid body motion of a two vertebra segment of the intact and *injured* C-spine. We will then stabilize the injury using current surgical techniques, i.e., interspinous wiring, segmental facet graft wiring, and segmental lamina graft wiring. We will also test segmental instrumentation of the Luque design, a one piece segmental instrumentation of our own design and future designs which we plan to develop.

**STATUS:** Several spines and fixation methods have been tested with the apparatus. A number of additional spines and devices are to be tested, to acheive statsistically significant data. Design work on new fixation methods is beginning.

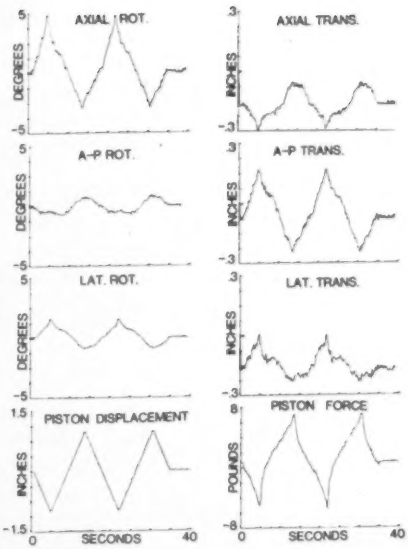


Figure 3. Sample data from two cycles of axial rotation loading. Show record of translational and rotational motion of C-4 relative to C-5. Record of force and displacement of piston is also shown.

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Project support: Merit Review
RR&D base resources and funds
April 1982 to April 1985

# MECHANICAL RESPONSE OF BONE


| | |
|---|---|
| DENNIS R. CARTER, Ph.D. | Principal investigator, VA and Stanford |
| WILLIAM E. CALER, B.S. | Co-investigator, Stanford |
| JOHN G. KENNEDY, M.S. | Co-investigator, VA and Stanford |
| BERNADETTE SQUIRE, B.S. | Co-investigator, Stanford |


**PROBLEM:** The intent of this study is to establish mathmatical models which predict the mechanical response (stress and strain fields) in long bones.

**BACKGROUND:** Clinical investigations have shown that a reduction of in vivo skeletal loading results in loss of bone mass, whereas increased skeletal loading causes a gain of bone mass (bone hypertrophy). Detail of the pattern of bone loss within a bone is believed to be directly related to the change in the strain field experienced within the bone. It is important, therefore, to generate mathmatical models which predict strain fields reliably in order to predict bone loss or gain.

**SIGNIFICANCE:** Strain induced remodeling has important implications in the practice of orthopaedics, since many orthopaedic procedures alter the forces applied to the skeleton. The rapid growth of implant surgery in recent years has caused concern about how the altered strain (or stress) fields in bone near the implant will influence the long term success of the implant procedure. In addition, knowledge of skeletal strain (or stress) fields are the basis of techniques used to predict the onset of static and fatigue failure in bones under monotonic or cyclic loading.

**HYPOTHESIS:** Bone remodeling is directly related to skeletal loading.

**APPROACH:** The strain distribution in a transverse plane of a long bone may be considered to be a superposition of normal strains (due to axial and bending loads) and shear strains (due to shear and torsional loads). The normal strains acting on a transverse plane in the diaphysis of the bone are calculated using the theory of biaxial bending of prismatic beams. The theoretical normal strain model is combined with in vitro strain recordings to establish the stiffness properties of the bone. Theoretical strain predictions and in vivo strain recordings are then combined to determine the in vivo strain (and stress) field and the internal load resultants within the bone.

The shear strains due to torsion acting in transverse planes is calculated using a finite element model based on two dimensional torsion theory. Theoretical stress predictions are combined with experimental strain recordings to establish the torsional shear modulus of the bone. The shear strain (or stress) field due to torsion is then calculated throughout the bone cross section. The accuracy of circular and elliptical annulus models of the bone cross-sectional geometry has been evaluated. The effects which transverse anisotropy, heterogeneity and longitudinal geometric variation have on the torsional response have also been evaluated.

These analytical techniques are used to compare strain fields to the biological activity within the bone. Such comparisons were conducted in canine radii and ulna as a part of this study. The biological response assessment was conducted using tetracycline labeling of the bone over various excercise periods (typically 8 weeks). The knowledge gained will improve our understanding of the contribution of mechancial forces and exercise activity to normal bone growth, turnover, osteopenia due to bed rest or "strain shielding" of bone with implants, hypertrophy in response to excercise and fatigue fracture.

**STATUS:** Reliable experimental and analytical techniques have been developed which provide a quantitative description of the mechanical response of long bones under both bending and torsional loads. The response due to shear loading has not yet been treated. Additional studies of the material and microstructural mechanics of bone are also needed.

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Project support: NIH Grant 32377
RR&D base resources and funding

## Neural and Muscular Systems Program Overview

The research of the Neural and Muscular Systems group is concentrated in three areas: (i) The biomechanical properties of the musculoskeletal system; (ii) The coordination of that sytem by peripheral and central neural mechanisms; and (iii) The development of diagnostic and restorative techniques pertinent to neural and muscular dysfunction. Experimental observations are used in synergism with mathematical and computer techniques in conducting this research. Current projects are:

- Development of new methods for rejoining severed nerves and clinically evaluating the subsequent neural regeneration.
- Determination of optimum functional electrical stimulation (FES) systems for restoring standing and walking to paraplegics.
- Characterization of the actual computations performed by spinal and brainstem circuits during the coordination of movement in able and disabled persons.
- Examination of the regenerative and adaptive capability of the nervous system for self-restoration following spinal cord injury or aging.

In the past year a technique, developed previously by us and which uses computer models and clinical measurements to estimate the number and size of fibers in a nerve, was tested in the neurology clinic at Stanford. These tests show that our new technique is more sensitive to changes in peripheral nerve composition than traditional methods. Our new technique is now used regularly in the clinic. Negotiations are ongoing with a manufacturer to market this technique by incorporating it into their existing product line for use by other neurology clinics.

Another recently developed technique also uses computer models but, in this case, to extract detailed information from electrical signals recorded during routine clinical examination of muscles. The implementation of this technique in a stand-alone, inexpensive microcomputer package is now being negotiated with a manufacturer.

# QUANTITATIVE EVALUATION OF NERVE REPAIR

VINCENT R. HENTZ, M.D. — Principal investigator, VA and Stanford
GORDON S. ABRAHAM, M.S. — Co-investigator, VA
KENNETH L. CUMMINS, Ph.D. — Co-investigator, Nicolet Biomedical Instruments, Madison, Wisconsin

**PROBLEM:** The treatment of peripheral nerve injuries rarely results in recovery of function adequately approaching that prior the the injury. In dealing with these injuries the physician faces two major problems. First, the lack of objective methods for assessing the extent of peripheral nerve injury, or the extent of regeneration in previously injured nerve compels physicians to rely on subjective criteria in making clinical decisions regarding the management of these injuries. Second, present methods of peripheral nerve repair, even those employing modern microsurgical techniques, rarely result in regeneration sufficient for full functional recovery. A number of adjuncts to traditional repair methods offer the promise of increased or directed regeneration, but the effectiveness of these new approaches need to be assessed objectively.

**SIGNIFICANCE:** The development of a simple method for evaluating the extent of a nerve injury will help the physician make objective decisions regarding the timing and type of care of the injured nerve. The use of the appropriate modality for the treatment of nerve injuries will enhance and speed the regenerative process and lead to fuller recovery of function.

**BACKGROUND:** Purely mechanical (suture) methods of re-approximating peripheral nerves result in very limited functional axonal regeneration. It is thought that this is due primarily to scar formation at the repair site, which prevents proximal axons from crossing the repair site and establishing functional connections. We have been studying sutureless repair methods that use biodegradable wraps to provide total circumferencial alignment of the nerve, block scar invasion at the repair site and improve the *milieux* for axonal regeneration. The preliminary results of our early investigation indicate that none of the purely mechanical alignment techniques hold any significant advantages to regeneration. Regeneration is being assessed using electrophysiological methods which estimate the number and velocity distribution (DCV) of axons both proximal and distal to the repair site. The analysis methods presently used require involved mathematical computation, and must be performed off line. Such evaluation methods are currently inappropriate for clinical use by physicians.

**HYPOTHESIS:** This project is based on two fundamental hypotheses. First, we feel that nerve function following injury, or axon regeneration following repair, can be reliably, quickly, and safely evaluated by electrophysiological methods which estimate the number and health of the axons crossing a focal lesion or repair site. In order for this tool to be generally applicable, it must be appropriate for both noninvasive and invasive (intra-operative) studies. Second, in order to enhance nerve regeneration in any significant and relaible fashion, modern mechanical repair methods will have to be coupled with other modalities that intrinsically influence the rate and/or direction of axonal regeneration (trophic factors), improve the axonal environment at the repair site (pseudoperineurial barriers), or decrease the effect of scar formation.

**APPROACH:** We are currently developing a simple technique for characterizing nerve function and regeneration at the repair site. This method estimates the number of axons that cross a focal lesion (or repair site) and their distribution of added conduction delays. This approach requires considerably less computation than DCV analysis. We are also investigating the possibility

of using magnetic recording and/or stimulating techniques for intra-operative evaluation of exposed nerve bundles. By employing magnetic coupling for recording, the practical problems of mechanical nerve damage, stimulus artifact, and operating-room ground loops will be minimized. The resulting signals, which reflect longitudinal current in the axons, can be analyzed using any of our methods of nerve evaluation. Initial experiments on magnetic measurement of action currents from rat sciatic nerve (performed in co-operation with John Wikswo, Ph.D., Vanderbilt University) have been quite promising. New innovations by Dr. Wikswo allow these measurements to be performed at room temperature using inexpensive equipment.

**STATUS:** Ongoing quantitative evaluation of nerve repair techniques include comparison of the use of nerve grafts versus repairing nerve under tension for segmental nerve loss, and use of various biocompatible materials as pseudoperineurial barriers. These investigations are being performed on a primate nerve model. Initial sudies of pharmacological agents, such as nerve-growth-factor, Cyclosporin A (an immunosuppressive drug) and Ibuprofen (a non-steroidal anti-inflammatory drug) are being performed on a rat peroneal nerve model.

The nerve repair techniques are being evaluated by the DCV approach. A method for characterizing focal delays and conduction block at the repair site has been developed and applied, with promising results, to a small number of repaired nerves. It is currently being evaluated on simulated data to determine its limitations. Initial tests of the neuromagnetic recording technique on injured nerve were encouraging. A new generation neuromagnetic system is being delivered in February 1984 ~~that~~ will circumvent the earlier problems of frequency compensation, drift and noise sensitivity.

The development of a useful nerve injury evaluation system and more effective nerve repair techniques will ultimately lead to greater functional recovery in man following nerve injury.

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Project support: Merit Review
RR&D base resources and funds
1979 to 1986



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# PERCEPTUAL AND MOTOR CORRELATES OF SOMATOSENSORY EVOKED POTENTIALS

RONALD W. ANGEL, M.D., Principal investigator, VA and Stanford
C. CURTIS BOYLLS, Ph.D., Co-investigator, VA
MICHAEL WEINRICH, M.D., Co-investigator, VA and Stanford

**PROBLEM:** Cortical somatosensory evoked potentials (SEP's), typically elicited by the electrical stimulation of peripheral nerves, have found wide use as a neurological diagnostic aid. However, this approach to the SEP usually bears little relation to any motor behavior of the individual under test, or to the perception of "natural" sensory cues. The potentials themselves also possess certain features, such as habitutation, whose neurophysiological substrate, behavioral correlates, and diagnostic significance have yet to be determined. We thus have undertaken a series of investigations to explore these issues both in normal adults and in selected populations of the neurologically disabled.

**SIGNIFICANCE:** As described below, the techniques we have developed attempt, via the SEP, to follow somatomotor signals through the perceptual process as they enter into the control of voluntary movement. Because we have little knowledge of how disordered sensory processing may enter into motor disability, we thus expect our work to open new opportunites for rehabilitation research.

**BACKGROUND:** For some years now, it has been appreciated that the presence of voluntary movement can change the perception of sensory stimuli. This principle is embedded in the idea of corollary motor discharge introduced by von Holst and Mittelstaedt, in the accounts of "sampled-data" processing contributed by Young and Stark, and in more recent studies of illusory motor sensations conducted by McCloskey, Rymer, and co-workers. In earlier work, the principal investigator, too, has found that perceptual thresholds for cutaneous sensation from a limb are elevated when that limb is voluntarily moved. The physiological substrate for these changes may lie in the inhibition of ascending lemniscal pathways during motor activity, as Ghez documented in cats.

In a study just published, we accumulated averaged evoked potentials over sensorimotor cortex following brief torque pulses at the wrist with and without the presence of voluntary movement. In nonmoving, neurologically normal subjects, these stimuli proved to elicit pronounced evoked potentials, whose latencies were largely independent of the direction of the triggering pulse of torque. However, when the subjects were asked to perform flexions or extensions of the elbow at moderate velocity, such evoked responses were greatly diminished, sometimes to the point of disappearing. At the same time, the subjects' ability to discriminate the direction of the brief torque pulse appeared to be significantly impaired—a task they had no difficulty with when not moving.

**HYPOTHESIS:** Our preliminary findings indicate that, in normal subjects, momentary loading or unloading of the wrist musculature is an effective producer of somatosensory evoked potentials within a "natural" motor-performance setting (this has also proved true at other joints; unpubiished observations). Furthermore, the movement-related reductions that we observe in these potentials seem tantalizingly correlated with the diminished ability of subjects to discriminate attributes of the stimulus.

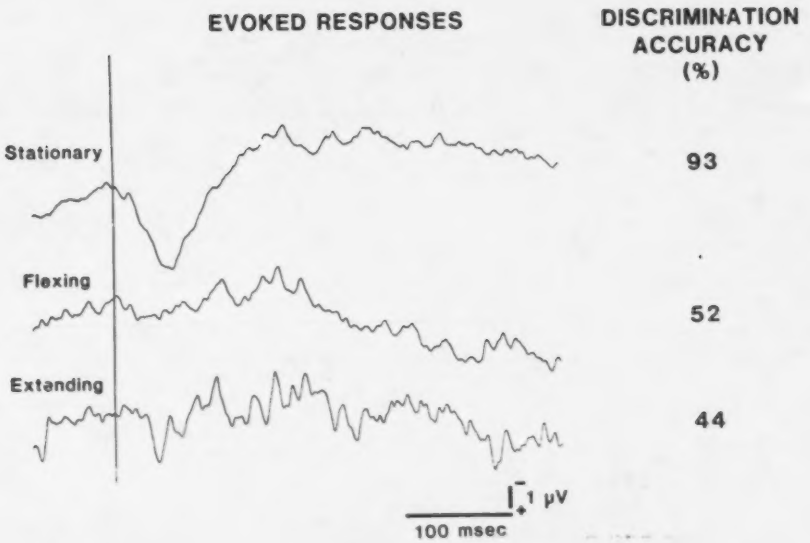


Figure 1. Effect of voluntary movement on SEP amplitudes and perceptual acuity. Each trace illustrates the SEP (average of 128 trials) recorded over the contralateral somatosensory cortex following brief (20 msec) torque perturbations delivered to the elbow at the time indicated by the vertical line. The perturbations are generated at random in either the "flexion" or "extension" directions, with blindfolded subjects required to report orally on the perceived direction of each. When the elbow is held stationary, a prominent SEP appears in the EEG (top trace), and discrimination accuracy approaches 100elbow flexions (middle trace) or extensions (bottom trace), the SEP's disappear and discrimination accuracy falls to chance levels. Further controls (see Boylls, et al., 1983, and Angel, et al., 1984, for details) suggest that this is a neural, not a mechanical, effect– perhaps a manifestation of attention-switching between the synthesis of motor efference and the perception of sensory afference.

We hypothesize that such degradation may occur because the normal motor control system rejects requests to attend both to movement command-generation and to sensory perception at the same time—and that, in certain neurological conditions, this supposed selective-attention ability may be compromised.

**APPROACH:** We shortly will be applying our evoked-potential paradigm to different neurological patient populations exhibiting motor deficits. Certain of these individuals will have proved lesions of sensory pathways resulting in disorders of limb sensation. Others, chosen among patients with Parkinsonism, cerebellar deficits, and drug-induced extrapyramidal syndromes, will have apparently normal somatosensation. The results obtained in the two populations will first be compared with cutaneous evoked-potentials elicited in the conventional clinical manner (i.e., electrically) to establish any diagnostic utility of the new technique. We then will explore alterations of the potentials as a function of movement and perception in each patient group. In addition, we have found that SEP's exhibit significant habituation following repetitive stimulation. It may be

that the recovery time course governing this process, by affecting somatic perception, enters into certain disease states; and we shall study the prospect in suitable experiments.

**STATUS:** The following reports have issued from this investigation:

- Rodnitzky, R.L., Angel, R.W., Weinrich, M., and Boylls, *C.C., Gating of somatosensory evoked potentials before voluntary movement.* Ann. Neurol. 14:140 (1983).
- Angel, R.W., Boylls, C.C., and Weinrich, M., *Cerebral evoked potentials and somatosensory perception.* Neurology 34: 123-126 (1984).
- Boylls, C.C., Angel, R.W., Rodnitzky, R.L., and Weinrich, M., *Assessment of neural strategies for the processing of somatosensory cues during voluntary movement.* Proc. 6th Ann. Conf. on Rehab. Engineering (San Diego, 1983), 307-308.
- Boylls, C.C., and Angel, R.W., *Utilization of somatosensory signals in the guidance of voluntary movement.* Bull. Prosth. Res. (in press).
- Angel, R.W., Boylls, C.C., Rodnitzky, R.L., and Rauch, R., *Decrement of somatosensory evoked potentials during repetitive stimulation.* Ann. Neurol. (submitted for publication).

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Project support: Merit Review
RR&D base resources and funds
January 1983 to September 1985

# OLIVOCEREBELLAR MECHANISMS OF MOTOR COORDINATION

C.CURTIS BOYLLS, Ph.D., Principal investigator, VA
JEAN H. ONYSKI, B.S., Biomedical engineer, VA
LISA A. COHEN, B.S., Research health scientist, VA

**PROBLEM:** Disease or injury of the supraspinal nervous system often results in disabling consequences for postural stability and gait. Improvement of rehabilitation techniques for such disabilities demands fundamental understanding both of supraspinal control strategies securing coordinated movement, and of the neural networks implementing those strategies.

**SIGNIFICANCE:** For reasons we shall describe, the understanding to be gained of the olivocerebellar role in locomotor coordination can be expected to provide considerable insight into how supraspinal structures are used to adapt motor performance to the outside world. Such knowledge should result in new techniques for restoring or restructuring such adaptation in individuals who lack it. Separate benefits may also follow from our use of sophisticated signal-processing algorithms, since such methods are becoming increasingly popular in analyzing a wide variety of normal and abnormal motor behaviors.

**BACKGROUND:** To study the supraspinal control of motor behavior, one ideally should begin with activity that is a well-documented and significant component of the motor repertoire. It next is important to find an experimental model that allows this activity to take place while neural processing within supraspinal structures can be observed. Lastly, as such observations are gathered, analysis methods are required which permit one to conclude how events occurring within the supraspinal CNS emerge to affect patterns of motor coordination.

In partial answer to the problems above, the locomotion exhibited by decerebrate mammals (rats, rabbits, cats, monkeys) has drawn the attention of numerous neurophysiologists and biomechanicians. The production of this behavior is believed to follow from the supraspinal and peripheral modification of basic stepping patterns generated by circuitry within the spinal cord. Using the high-decerebrate cat, Orlovsky, Udo, and others have demonstrated that the cerebellum originates much of that supraspinal influence, acting through the multitude of descending pathways it oversees. This conclusion is consistent with the established cerebellar role in human motor coordination.

Earlier work we performed examined in detail how decerebrate locomotion in cats is regulated by one major cerebellar substructure, the olivocerebellar pathway linking the inferior olivary nucleus of the medulla to the cerebellum. The evidence obtained suggested that olivocerebellar activity is a prime regulator of the basic posture adopted by the walking animal. Moreover, we found that the olivocerebellar system seems to have a "memory" for particular postures, indicating that the system might serve as a gyroscope-like, internal reference for postural stability.

**HYPOTHESIS:** The possibility that motor tasks are guided by an internal postural reference would, if true, figure heavily in any framework for understanding posture and gait disorders. To investigate the issue further, we have exploited results from oculomotor studies to conjecture that the olivocerebellar system determines which postural reference to favor by monitoring the "mismatch" between spinally-generated motor commands and the actual movements produced. The proposition is testable in the walking decerebrate cat.

**APPROACH:** Our prior investigations, which demonstrated the feasibility of studying cerebellar and brainstem mechanisms during decerebrate locomotion, relied primarily upon

extracellular unitary recording and microstimulation techniques. More recently, however, we have developed so-called spike-triggered averaging methods to establish both the connectivity and physiological influence between different neurons in the olivocerebellar system. These methods utilize correlations computed between the spontaneous activities of simultaneously recorded cells. Such correlations can be used to construct computer models that define and predict the cells' behaviors. We believe, therefore, that this tactic will allow us to analyze the olivocerebellar regulation of posture without having to disrupt the system's natural processing with microstimulation, lesioning, or similar intervention.

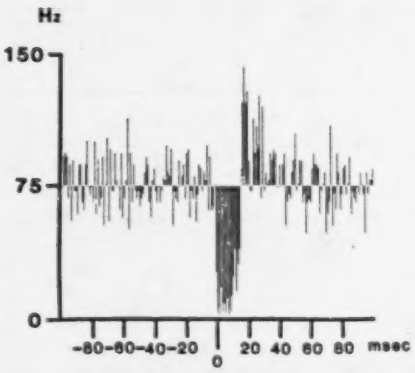


Figure 1. Early components of the Purkinje cell response to a spontaneous olivocerebellar volley (average of 324 such volleys, occurring at a mean rate of 0.55 Hz). Prior to the occurrence of the olivocerebellar input at 0 msec, the Purkinje cell maintains a discharge rate of approximately 75 Hz. The olivocerebellar volley momentarily silences the cell; but after 20 msec, the discharge rebounds and subsequently appears to return to its previous rate. This behavior has been known for more than two decades and was thought to comprise the "complete" physiological response of the cerebellum to olivocerebellar inputs—even though it has proved difficult to link such responses to any attribute of motor coordination with which the cerebellum deals.

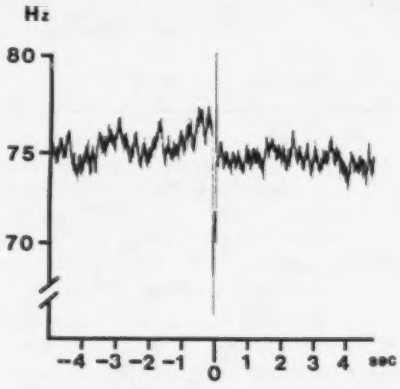


Figure 2. Late aftereffect of an olivocerebellar volley on the Purkinje cell shown in the previous figure. The data have been analyzed using linear prediction and filtering techniques (Boylls, et al., in preparation), which reveal a prolonged depression of Purkinje activity following upon the early response to the olivocerebellar input (note time scale in seconds). While this effect is slight after individual olivocerebellar volleys, it accumulates significantly when volleys occur repetitively over time during motor performances. We have been able to link this "short-term memory" with a powerful brainstem-cerebellar mechanism for regulating postural equilibrium (Boylls, 1982a,b).

During the past year, spike-triggered averaging has been employed to deduce the influence of spontaneous olivocerebellar volleys upon the activity in Purkinje cells– whose axons carry the output from the cerebellar cortex. Averaging, followed by calculations using least-squares linear-estimator techniques, has revealed seconds-long alterations in Purkinje discharge profiles following olivocerebellar activity; and we believe these alterations to be the physiological substrate for the "gyroscope-like", postural influence mentioned above. We now intend to apply the same methods to examine more explicitly the correlation between postural adjustments and olivocerebellar activity. Specific concentration will be upon pathways regulating processing in the descending vestibulospinal

system, a principal governor of postural equilibrium in both cats and humans. Thereafter, we plan a direct test of the hypothesis above by observing olivocerebellar reactions to controllable "mismatches" between spinally-generated locomotor commands and actual movement feedback.

**STATUS:** The following reports have issued from this investigation:

- Boylls, C.C., *Internal directional reference frames for motor coordination.* Proc. 4th Ann. Conf. of the Cognitive Science Society, U. Michigan (Ann Arbor, 1982), pp. 22-23 (invited contribution).
- Boylls, C.C., *Climbing fibers and the spatial reference frame for motor coordination.* In: Arbib, M.A. (ed.), Proc. Workshop on Visuomotor Coordination in Frog and Toad: Models and Experiments, COINS Technical Report 82-16, U. Massachusetts (Amherst, 1982), 23 pp. (invited contribution).
- Boylls, C.C., and Greene, P.H., *Bernstein's significance today.* In: Whiting, H.T.A. (ed.), Human Motor Actions: Bernstein Reassessed, Elsevier (Amsterdam), in press (invited contribution).
- Boylls, C.C., Onyski, J.H., and Cohen, L.A., *Association of spontaneous climbing fiber volleys with seconds-long changes in Purkinje cell simple spike activity.* In preparation.

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Project support: Merit Review
RR&D base resources and funds
October 1982 to September 1985

# COMPUTER MODELS FOR DESIGNING FUNCTIONAL ELECTRICAL STIMULATION SYSTEMS FOR PARAPLEGIC STANDING AND WALKING

FELIX E. ZAJAC, Ph.D. — Principal investigator, VA and Stanford
INDER PERKASH, M.D. — Co-investigator, VA and Stanford
WILLIAM DWAN, B.S. — Computer programmer, VA

**PROBLEM:** Persons with spinal cord injury resulting in paraplegia need to regain functional use of their legs.

**SIGNIFICANCE:** Rehabilitation of the spinal cord injured person is a high priority of the VA.

**BACKGROUND:** Functional Electrical Stimulation (FES) of paralyzed muscles is potentially a useful method for restoring standing and walking in paraplegics. Problems exist, however, that must be solved before FES becomes clinically acceptable as a mechanism for restoring mobility to paraplegics. These problems include unreliable stimulating electrodes, insufficient muscle strength and fatigue resistance of the paralyzed muscles, and unavailibility of a totally implantable stimulation system.

**HYPOTHESIS:** Another major problem is the lack of suitable engineering models to study the trade-offs of different FES schemes proposed for controlling paraplegic standing and walking. We hypothesize that the use of large scale computer models based on engineering principles is essential to the systematic development of FES systems, just as such models are neceassary in controlling aircraft, satellites, robots, and in planning economic policy.

**APPROACH:** Our engineering model is based on properties of the musculoskeletal system. The model includes the dynamics of the body, which is considered to consist of at least seven skeletal segments. The model also incorporates dynamics of muscles. Computer-implementation and graphics are deemed essential for effective use by the rehabilitation team.

**STATUS:** We have developed an approach to modeling muscle that is based on the fundamental architectural properties of muscle and tendon. Computer-implementation of the dynamics of ten leg muscles is ongoing. Skeletal dynamics have been developed for standing (legs in sychrony), assuming that no assistive aids are used by the standing person. We will next increase model complexity to include more muscles and assistive devices, as an option, in the computer program.

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Project support: RR&D base resources and funds
NIH grant NS 17662
October 1982 to present

# INTERMUSCULAR COORDINATION OF MAMMALIAN MOVEMENT


| | |
|---|---|
| FELIX ZAJAC, Ph.D. | Principal investigator, VA and Stanford |
| WILLIAM LEVINE, Ph.D. | Co-investigator, University of Maryland |
| C. CURTIS BOYLLS, Ph.D. | Co-investigator, VA |
| MICHAEL ZOMLEFER, Ph.D. | Co-investigator, VA |
| JEAN ONYSKI, B.S. | Biomedical Engineer, VA |
| LISA COHEN, B.S. | Research Health Scientist, VA |
| WILLIAM DWAN, B.S. | Computer programmer, VA |


**PROBLEM:** Rehabilitation of persons with severe motor disorders is difficult because our understanding of the basic mechanisms coordinating multi-jointed movement is limited. However, the understanding of neural mechanisms used to coordinate muscles is, at the moment, highly speculative and qualitative because neural programming of even the simplest movement is complex. Thus, the problem is to develop analysis techniques applicable to the study of complex motor tasks.

**SIGNIFICANCE:** The analytical, computational and experimental framework developed in this project will be useful to studies of posture and walking. The optimal control approach being developed has potential clinical use in suggesting optimal strategies for rehabilitative training and physical therapy, for reconstructive orthopaedic surgery, for functional electrical stimulation of paralyzed muscles, and for orthotic and prosthetic design.

**BACKGROUND:** Motor control physiologists studying body motion have focused on understanding single-joint movement using electromyographic, kinesiological, single unit and in vivo force recordings. Except for descriptions of the neuromuscular events correlated with the movement under study, these studies have resulted in few predictive theories for motor control. On the other hand, biomechanicians have studied movement by computing joint torques and forces from measurements of body motion using as a basis dynamical models of multi- jointed structures. While such studies have been particularly fruitful in the design of artificial joints, they have had limited success in estimating individual muscular forces occurring during movement.

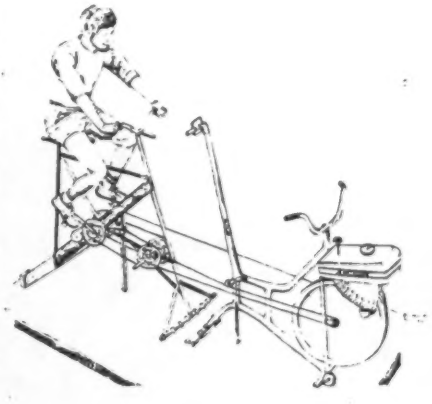

Figure 1.

**HYPOTHESIS:** Optimization theory applied to neuromuscular control has the potential to define the pattern by which single muscles ought to be coordinated for the body to achieve a specific motor task for any given constraint imposed on the nervous system command structure and the musculoskeletal system.

**APPROACH:** Our previous work has been to identify jumping as a task for which the performance criterion is rather precisely specified. This has enabled us to develop optimal control theory techniques to find how muscles ought to be coordinated for the body to move and attain, in

this case, maximum height jumps. The approach uses a symbiosis of physiological, biomechanical and control theory methods.

**STATUS:** We have broadened our model so that it has four limb segments and seven leg muscles. The optimization techniques have also been expanded to include this more complex musculoskeletal model. Our current efforts are focused on understanding the energetics of propulsion; specifically, the role of tendon and muscle elasticity as a mechanism of storing energy that can later be recaptured and in used in propulsion. This knowledge will be used to assess how elasticity can be best utilized to effect efficient walking in able and disabled persons.

We have also begun to study interlimb coordination during bipedal cycling. A custom gearing mechanism and frame was designed, built and connected to a commercial ergometer (Fig. 1). This apparatus allows us to compare coordination of the two legs during conventional pedaling, when the cranks are 180 (degrees) out of phase, with coordination during novel pedaling, when the cranks are, say, 90 (degrees) out of phase. Other novel arrangements are also possible. For example, one leg can be forced to pedal at a velocity different from the velocity of the other leg. Preliminary experiments on able-bodied subjects have begun. In the future we plan to adapt the apparatus to study spinal reflexes in paraplegics during pedaling induced by functional electrical stimulation (FES).

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Project support: National Institutes of Health
RR&D base resources and funds
July 1980 to June 1984

# AUTOMATIC DECOMPOSITION OF THE CLINICAL ELECTROMYOGRAM

LESLIE J. DORFMAN, M.D. — Principal investigator, VA and Stanford
KEVIN C. MCGILL, M.S. — Co-investigator, VA and Stanford

**PROBLEM:** The electromyographic (EMG) examination plays an important role in the diagnostic evaluation of many neuromuscular disorders. It involves recording an electrical signal from a contracting muscle using a needle electrode. In current practice most neurologists assess EMG signals in a way that is qualitative and subjective—by listening to their sound and by watching their pattern as they flash across an oscilloscope screen in real time.

**SIGNIFICANCE:** There is a widely felt need for a quantitative method for analyzing EMG signals which would be more objective, more reproducible, and, hopefully, more diagnostically sensitive than the subjective methods in current use.

**BACKGROUND:** There have been two major approaches to quantitative EMG analysis. The first approach has been to decompose the signal into its component motor-unit action potentials (MUAPs). This approach has proven to be diagnostically sensitive, but it is limited to weak contractions because of the difficulty of decomposing high-force EMG signals—commonly called "interference patterns" because of their resemblance to random noise. The second approach has been to try to characterize high-force interference patterns statistically, for example by their power spectral density. This approach has proven to be insensitive and unreliable. At present, no method of quantitative EMG analysis has gained wide acceptance.

**HYPOTHESIS:** We hypothesized that advanced signal-processing techniques could be employed to efficiently and accurately decompose moderately complex EMG interference patterns into their component MUAPs.

Fig. 1 **Top:** 2.5-s EMG interference pattern recorded from a healthy human biceps during a moderately strong contraction. **Bottom:** The same signal after digital filtering. The filter accentuates the MUAP spikes and suppresses the baseline noise. The spikes corresponding to the six largest MUAPs have been identified by our program.

**APPROACH:** We have written a computer program for extracting MUAPs from EMG signals recorded during conventional EMG examinations. The program achieves greater speed and accuracy than existing EMG analysis methods through the use of four innovative signal-processing techniques: (i) a fast digital filter for transforming MUAPs into sharp spikes which can be easily detected and accurately identified (Fig. 1); (ii) an efficient algorithm for aligning and comparing spikes which achieves high temporal resolution at a low sampling rate; (iii) a method for verifying or rejecting tentatively identified MUAP trains based on the regularity of their interspike intervals; and (iv) a new noise-reducing algorithm for back-averaging the MUAP waveforms from the raw signal using their identified spikes as triggers (Fig. 2). The program can analyze a 10-second EMG signal in five minutes of computation time and is able to decompose signals containing as many as 15 MUAP trains. We believe we will be able to increase the program's speed to allow on-line operation.

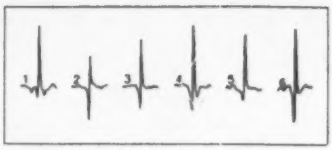


Fig. 2. Estimates of the MUAP waveforms from Fig. 1 obtained by back-averaging using the identified spikes as triggers.

**STATUS:** We have implemented the automatic EMG decompositon method using a PDP-11/34 minicomputer at Stanford Medical Center's EMG Laboratory, and are currently evaluating it by collecting a data base of MUAP properties from healthy subjects and patients with known neuromuscluar disorders.

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Project support: RR&D base resources and funds
1981 to 1984

# THE SPINAL LOCOMOTION PATTERN GENERATOR IN HUMANS

MICHAEL R. ZOMLEFER, Ph.D. — Principal investigator, VA
RONALD F. GAINES, M.D. — Co-investigator, VA
EARL H. BISHOP, B.S. — Biomedical Technician, VA

**PROBLEM:** Current techniques to restore locomotor function in spinal cord injured patients have revolved about either the use of external mechanical aids (walkers, crutches, canes, etc.) or, more recently, the use of functional electrical stimulation to activate select groups of lower limb muscles. For a combination of technical and cosmetic reasons, these approaches have, in general, not led to restoration of walking for the disabled community. All of these solutions chose to ignore the possible presence of any intact spinal cord control of lower limb muscles.

**SIGNIFICANCE:** The outcome of this proposed work will have a significant impact on the course of future spinal stepping experiments in both humans and animals. The absence of locomotor activity in humans would force neurophysiologists to re-examine existing models for spinal cord injury, and perhaps work more extensively with preparations that better resemble those found in spinal cord injured humans. On the other hand, the presence of spinal stepping in our subjects would strengthen the relevance of existing animal work in the area,and create the framework for more quantitative studies with human subjects. Evidence leading to the existence of spinal "locomotor pattern generators" would be an exciting development ... suggesting the possibility of simple controllers for the generation of locomotion in humans with cord injuries.

**BACKGROUND:** Extensive experimental work over the past few decades has shown that many mammals (e.g., dogs, cats, rabbits, rats) can perform stepping locomotor activity after a complete spinal cord transection. These spinal stepping experiments have led to a much better understanding of spinal cord function in the control of locomotion. However, one investigator's attempt to extend this experimental work to primates has failed to elicit rhythmic limb activity. There have been few reported attempts in the literature to systematically observe the presence (or absence) of stepping in spinal cord injured patients. It is therefore unknown whether human subjects with spinal cord transections can perform rhythmic stepping movements with their legs suspended above a moving treadmill.

**HYPOTHESIS:** It is the thesis of this study that humans possess some form of spinal "pattern generator" for locomotion.

**APPROACH:** Volunteer patients are suspended in amodified parachute harness over a moving treadmill belt. The sole stimulus to the patient will be plantar contact of the foot with the belt. Any leg movement will be recorded with a video system, while electromyographic activity will also be measured from lower limb muscles.

**STATUS:** To date, approximately two dozen patients have been tested in the first year of this study. A preliminary report has been published (Society for Neuroscience) and a full paper is in preparation.

| SUBJECT# | AGE IN YEARS | YEARS SINCE INJURY | LEVEL OF INJURY | MOTOR /SENSORY† | SPASM /TONE‡ |
|---|---|---|---|---|---|
| 01 | 42 | 15.00 | T3 | */* | mi |
| 02◇ | 47 | 1.00 | T8 | */* | mi |
| 03 | 35 | 0.83 | T3 | */* | mo |
| 04 | 53 | 1.00 | T12 | */* | f |
| 05◇ | 36 | 2.25 | T1 | */ | mi-mo |
| 06◇ | 40 | 0.33 | T5 | */* | mo |
| 07⊙ | 28 | 0.25 | T5 | */* | mi-mo |
| 08◇ | 53 | 0.50 | T11 | */* | mi |
| 09◇ | 49 | 25.00 | T5 | */ | mi |
| 10 | 19 | 0.67 | T5 | */ | mo |
| 11◇ | 21 | 0.38 | T10 | */* | f |
| 12 | 43 | 2.67 | T11 | */* | f |
| 13◇ | 21 | 0.25 | T5 | */* | mi-mo |
| 14 | 30 | 10.25 | T5 | */ | mi |
| 15◇ | 24 | 0.38 | L1 | */ | mi |
| 16 | 26 | 7.50 | T10 | */* | mo |
| 17 | 34 | 11.00 | T4 | */ | mo |
| 18◇ | 28 | 3.42 | L1 | */* | mo |
| 19◇ | 36 | 3.25 | T6 | */ | mi-mo |
| 20 | 44 | 6.50 | T6 | */ | mi |
| 21 | 56 | 0.83 | T8 | */* | mo |
| 22 | 26 | 2.00 | T8 | */* | mi |
| 23 | 49 | 23.00 | L1 | */* | mi |
| 24 | 37 | 11.50 | T8 | */* | mi |
| 25 | 43 | 6.67 | T11 | */* | mi |

† *=complete ‡ mi=mild mo=moderate f=flaccid

Table 1. A total of 25 subjects have been tested, ranging in age from 19-56 yrs (36.8 ±3.3). The date of injury preceded the testing date by periods extending from 0.25-25.0 yrs (5.46 ±2.65). Ten subjects (◇) showed bilateral EMG patterns similar to those found in normal locomotion when their legs were externally driven. Additionally, one subject (⊙) developed alternating, rhythmic leg EMG activity when his legs were held suspended and motionless above the treadmill.

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Project support: RR&D base resources and funding

# NERVE-BUNDLE CONDUCTION VELOCITY DISTRIBUTIONS:
## Clinical and Research Applications

LESLIE J. DORFMAN, M.D. — Principal investigator, VA and Stanford
KEVIN C. MCGILL, M.S. — Co-investigator, VA and Stanford
KENNETH L. CUMMINS, Ph.D. — Co-investigator, VA, Stanford and Nicolet Biomedical Corp.

**PROBLEM:** Measurement of nerve conduction velocity (NCV) is an important element in the electrophysiological evaluation of patients with suspected neuromuscular disorders. Conventional methods of determining NCV focus predominantly or exclusively upon the velocity of the fastest-conducting (largest-diameter) fibers in the nerve bundle.

**SIGNIFICANCE:** The capability to measure the conduction velocities of all the different classes of nerve fibers comprising the nerve bundle may be expected to enhance the sensitivity and specificity of electrodiagnosis, and to improve treatment of neuromuscular disability.

**BACKGROUND:** We have developed a computer-based method for estimating the distribution of conduction velocities (DCV) in the subpopulation of large myelinated fibers comprising human peripheral nerves. This method is superior to others by virtue of its generality and its suitability for clinical implementation.

**HYPOTHESIS:** (1) That clinical trials of DCV analysis will confirm its diagnostic superiority to conventional NCV methods; (2) that DCV analysis will yield insights into the pathophysiology of neuromuscular disorders; (3) that DCV analysis may bbe implemented on existing electroneuromyographic equipment, so as to be more widely available for evaluating patients with neuromuscular disabilities.

**APPROACH:** DCV analysis has been carried out in normal subjects and in patients with diabetic neuropathy, carpal tunnel syndrome, amyotrophic lateral sclerosis, multiple sclerosis, cerebral infarction, and other conditions; and has been contrasted with conventional NCV results in these same individuals. Different methods of DCV analysis have been compared in normals and patients. DCV analysis has been implemented on a commercial electroneuromyograph.

**STATUS:** Five journal papers and one book published; three more papers in preparation. Clinical trials are transitioning into regular clinical use at Stanford laboratory. Discussions ongoing regarding commercial distribution of this technology.

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Project support: Muscular Dystrophy Association
RR&D base resources and funds
1978 to 1983

## Human Machine Integration Systems Program Overview

The Human Machine Integration Program is dedicated to the development of tools that augment the functional independence of disabled people. Typically, we are not concerned with changing the individual's disability status, but we are very concerned with reducing the handicap often associated with disability. An emphasis is placed on functional rather than anatomical problem definition. Whereas other RR&D programs are appropriately concerned with enhancing the physiological performance of the body, we seek to extend performance through external assistive devices.

While open to the widest possible array of product proposals and technology, we have tended to see computers as our primary R&D tool and microprocessors as the key ingredient in a new class of "smart" products that are capable of adapting to their environment and user. This feature and philosophy are primary criteria in our project selection process. Then, with a NEED firmly established and understood, the prospective project is examined in terms of its generality. Would individuals with different disabilities find the product useful, and would non-disabled users also benefit from its existence to the extent that we are working towards the largest possible market and the lowest probable cost to the end user.

One other feature of our approach needs mention. We work hard to integrate product development and product evaluation. In this context, formal procedures are used to obtain the earliest possible user feedback on device prototypes. Though difficult to obtain, user feedback at this early (formative) stage in the evolution of an assistive device can have a profound effect on the direction content of the R&D process. Most importantly, we are further assured that, when the product is ready, we know who needs it, who will prescribe it, and who will buy it.

While individual project abstracts will give you a clear indication of our activity, the following broad areas of emphasis have evolved over the past four years in response to the human needs and problems we have encountered, and to the human resources we have been able to engage in solving them.

- Manipulation Aids
- Mobility Aids
- Visual Perception Aids
- Cognitive Aids
- Evaluation Methodology

# DEVELOPMENT OF A GRAPHIC BRAILLE DISPLAY


| | |
|---|---|
| GREGORY L. GOODRICH, Ph.D. | Principal investigator, VA and University of California, Berkeley |
| DOUGLAS MAURE, B.S. | Co-investigator, American Foundation for the Blind, New York |
| SUE L. MELROSE, M.A. | Co-investigator, VA |
| DAVID L. JAFFE, M.S. | Co-investigator, VA |
| ELLIOT SCHRIER, B.S. | Co-investigator, American Foundation for the Blind, New York |
| MICHAEL STEVENS, B.S. | Co-investigator, American Foundation for the Blind, New York |


**PROBLEM:** Computers are rapidly becoming prerequisites for educational and vocational opportunities. There are numerous public and private groups actively seeking means of making computers accessible to the visually impaired. The most common means of access are synthetic voice ouputs, single-line refreshable braille displays, and large print displays. None of these provide access to graphic information (e.g., bar graphs, pie charts, histograms, etc.). Thus, there is a pressing need to make such graphic information accessible to the visually impaired.

A means of presenting such information would have numerous other applications (for example, in presenting trigonometric and geometric mathmatics, geographic maps, flow charts, organizational charts, and diagrams of instruments, buildings and equipment). These applications are relevant to all visually impaired individuals, regardless of age or occupation.

**SIGNIFICANCE:** The four blind rehabilitation centers of the Veterans Administration routinely provide training on a variety of computer related devices. Most of this training is directly related to the veterans vocational or educational objectives. Current training is often restricted to programming or word processing tasks because of the lack of a suitable means of presenting graphic and/or tabular materials. The development of a tactile, graphic display would significantly improve the ability of these centers to provide comprehensive training in the use of adapted computer aids.

The development of such a display would also be directly applicable to many non-veterans who have severe visual impairments. Current estimates indicate that over 60,000 veterans and over 1.5 million non-veterans are blind. It is conservatively estimated that the development of a low-cost, accessible tactile display would significantly improve the educational and vocational opportunities of thousands of individuals.

**BACKGROUND:** Since 1981 the Western Blind Rehabilitation Center (VAMC, Palo Alto) has been providing training in the use of adapted computer aids. More recently the Center has entered into a cooperative program with the Sensory Aids Foundation of Palo Alto to offer an expanded training program to visually impaired veterans and non-veterans and to rehabilitation professionals who need such knowledge to effectively work with their own clients. The Center also has some 7 years experience in research and evaluation of computer aids for the visually impaired. Much of this work has been a cooperative endeavor between the Western Blind Rehabilitation Center and the Rehabilitation Research and Development Center.

The American Foundation for the Blind has recently designed a graphic braille display which is thought to be suitable for providing graphic and alphanumeric information. The current project will allow continued development of the display, the development of needed software, and evaluations of the display in both laboratory and field testing conditions.

section 6.3.1

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**APPROACH:** The research will combine hardware and software development with concurrent evaluation so that the design process can immediately benefit from information obtained in the evaluation process. This will be facilitated by the initial construction of three prototype displays. This will allow two displays to be used for field and laboratory testing and one prototype to be used for hardware refinement. The three units can be rotated (from the American Foundation for the Blind to the Western Blind Rehabilitation Center) so that advances in hardware are immediately incorporated into the evaluation without the loss of time typically encountered when prototypes malfunction or are returned for modification. Software development will focus on Apple II+ and IIe computers and on CP/M based systems. These encompass the most widely used computers.

**STATUS:** The project received merit review approval in December 1983 and is currently awaiting the availability of funds (anticipated in October 1984).

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Project support: RR&D base resources and funds
Merit Review
Begin October 1984

# A LIFE-SPAN APPROACH TO PRODUCT DESIGN AND DEVELOPMENT FOR THE AGING POPULATION


| | |
|---|---|
| K.G. ENGELHARDT, A.B., B.A. | Principal investigator, VA |
| PAUL HABER, M.D. | Investigator, VA |
| LARRY LEIFER, Ph.D. | Investigator, VA and Stanford |
| KAREN HOLLOWAY, B.S. | Biomedical engineer, VA |
| ROGER AWAD, M.S. | Research Health Scientist, VA |


**PROBLEM:** The demography of the United States is changing rapidly as the older segment of the population increases. As a result, the needs, wants and capabilities of the average user are changing too. This will soon necessitate the reassessment of the standards by which products are now developed and evaluated. The human factors profile currently used by designers is based on the ergonometric and anthropometric characteristics of a 21-30 year old male. Less than ten percent of all older adults match this profile. There is a need for a human factors profile that takes into account the human values and the physical characteristics of the aging population.

**SIGNIFICANCE:** The importance of designing from a broader perspective, using a life-span approach to design and development, is consistent with the goals of human factors research. The Rehabilitation Research and Development evaluation team adheres to this definition, and accordingly, seeks to optimize the relationship between the human and technology. The Interactive Evaluation Model, developed by Engelhardt, et al., is evidence of this concern. In addition, this Center takes an *"intergenerational approach to research, design , development, evaluation, and dissemination of prototypes and products"* to *"foster greater independence for persons regardless of age"* (Engelhardt, Leifer 1984).

**BACKGROUND:** In this decade we have experienced both an incredible growth in micro-electronic technology and a great increase in the older population. The characteristics of microprocessor based technology are such that it can be used to meet the needs of the elderly. Its flexibility and modularity can be helpful in solving problems that were unaddressable ten years ago.

**HYPOTHESIS:** We hypothesize that technology developed through an interactive process and coupled with an approach to design and development based on a lifetime continuum, will be more appropriate to, and therefore more accepted by, the end-user population. This interactive process requires user involvement at all stages of the development cycle. It is believed that user-focused research will insure a well defined need statement, which is necessary to optimize the relationship between human and machine and will aid in the diffusion process.

**APPROACH:** The Interactive Evaluation Model is used to focus on a life-span approach to product design and development. The project seeks to: (1) involve student design engineers and older people in intergenerational needfinding and design; (2) provide students with a broader perspective to design and development; (3) develop methodologies to better educate engineering design students to meet the needs of older users; (4) develop a model from structuring communication between users and designers; (5) develop criteria for evaluation of marketed assistive devices; (6) provide feedback to manufacturers of assistive devices; (7) facilitate interaction between academia, industry and government; and, (8) identify new projects which promise to benefit the aging through the application of microcomputer technology.

**STATUS:** The VA RR&D and the Stanford University Mechanical Engineering Design Division have collaborated on two student projects in the past year. Both were designed to highlight the needs of the elderly and to educate the students in a life–span approach to design. In one of the VA/Stanford projects, the interaction between academia, government and industry was of primary concern. This interaction is continuing as the manufacturer considers the student ideas in the upcoming redesign of their product. In the evaluation effort, retired professionals are involved in the identification of needs and definition of appropriate technology for their peers. Currently a computer class at one of the local senior centers (average age of the programmers: 69) is helping in the evaluation of a commercial robot for use by the infirmed. Other seniors are serving as advisors and community liaisons for a project in needfinding at Stanford. The results of this research will be presented at the 30th Annual Meeting of the Western Gerontological Society in March of this year. (Holloway, Engelhardt 1984)

Lifeline Personal Help Button

1. wearable at all times
2. waterproof
3. small
4. lightweight
5. aesthetically pleasing
6. easy to activate
7. low cost
8. long-lived (disposable/replaceable)
9. potential for personalization
10. safe (edges/points)
11. feedback on switch activation
12. feedback on power supply

Figure 1. Criteria designed for evaluation of student re-designs of the Lifeline Personal Help Button.

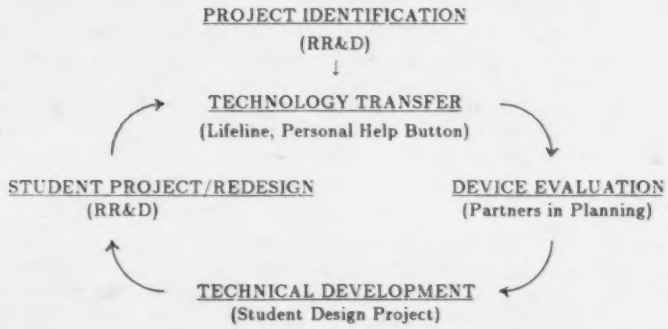


Figure 2. Lifeline project as it fits into the framework of the Interactive Evaluation Model.

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Project support: RR&D base resources and funds
October 1981 to September 1984

# WHEELCHAIR FEEDBACK CONTROLLERS


| | |
|---|---|
| ROBERT SMITH, M.S. | Acting principal investigator, VA |
| INDER PERKASH, M.D. | Co-investigator, VA |
| LARRY LEIFER, Ph.D. | Co-investigator, VA and Stanford |
| DOUGLAS IVES, M.S. | Co-investigator, VA |
| DAVID NAPOLITANO, M.S. | Co-investigator, VA |
| STEVEN SHINDELL, Ph.D. | Co-investigator, VA |


**PROBLEM:** Users of electric wheelchairs often have difficulty controlling their mobility device due to its poor response. Most current electric wheelchair controllers operate in an open-loop mode, providing no compensation for disturbances affecting the wheel speeds. Electric wheelchair users frequently encounter situations which cause unwanted variations in both the velocity and the direction of their wheelchair. Traveling on hills and sides of slopes, and maneuvering on carpet and across bumps are examples of situations which impose a heavy control burden upon the wheelchair user.

**SIGNIFICANCE:** Improvements in the handling of electric wheelchairs both indoors and outdoors will be facilitated by this research. The development of a broad-based digital controller will provide people having minimal muscular control the means of controlling a wheelchair, thereby making wheelchairs useable by a greater portion of the disabled population. It will also enable the new generation of omnidirectional wheelchairs to be practical and controllable. Evaluation of controller performance will provide a more accurate understanding of the ergonometric aspects of wheelchair control and the effectiveness of various control schemes.

**BACKGROUND:** Invacare Corporation is marketing an electric wheelchair with feedback control using motor voltage and current information processed by electronic circuitry based on discrete components. A number of research groups are studying microprocessor-based feedback controllers with wheel velocity sensors. Work has been done at U.C. Berkeley on the modeling and computer simulation of a conventional electric wheelchair with its control system, and with a closed-loop controller. Concurrent with the design of microprocessor-based controllers and control schemes for wheelchairs, the present project seeks to develop good dynamic models of two types of wheelchairs: the three-wheel drive omnidirectional vehicle developed at the RR&D Center, and the conventional two-wheel drive powered wheelchair.

**HYPOTHESIS:** A velocity feedback controller should provide greatly improved response compared to an open-loop controller. The questions are what feedback algorithm to use, what parameters should be sensed to achieve the desired control, whether a microprocessor is the indicated hardware, and how to measure the effectiveness of individual schemes.

**APPROACH:** The VA controller project uses the technologies and methodologies of electric motor control, power electronics, digital control theory, ergonometrics, and system evaluation. The project's specific objectives include: (1) design and development of solid-state power bridges suitable for providing power from wheelchair batteries to DC motors; (2) design and development of microprocessor-based controller hardware suitable for an omnidirectional wheelchair; (3) development of control software for an omnidirectional wheelchair; (4) implementation of power bridges, controller hardware, and controller software on Alexis, an omnidirectional wheelchair; (5) design and development of a microprocessor-based controller module suitable for use on the spectrum of conventional two-wheel drive electric wheelchairs; (6)

development of controller software for conventional wheelchairs; (7) packaging of power bridges and controller hardware into a stand-alone module; (8) implementation of power bridge/controller module on a conventional electric wheelchair; (9) evaluation of controller performance for omnidirectional and conventional wheelchair applications; and (10) documentation of results in form suitable for manufacturers' use.

**STATUS:** The controller development for the omnidirectional wheelchair has been completed; the design is serving as the basis of a controller now being developed commercially. Evaluation of the Alexis controller will proceed as prototypes become available. Current emphasis is upon determining the relevancy of various factors to wheelchair control, as well as the development of the controller for conventional electric wheelchairs. Evaluation of this controller will follow soon after its implementation.

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Project support: Merit Review
RR&D base resources and funds
October 1982 to September 1984

# ULTRASONIC HEAD CONTROL UNIT

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INDER PERKASH, M.D. — Co-investigator, VA
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**PROBLEM:** Quadriplegics and others lacking control of upper and lower limbs have a need for improved communication and control of their enviroment.

While many interfaces have been developed for use by severely disabled individuals, none are ideal; some have sanitation problems (pneumatic puff/sip switches), while others may physically intrude upon the user (chin operated joysticks) or may be socially objectionable (head wands). Technologically advanced approaches have drawbacks of their own: eye control units restrict the user's gaze unduly, while voice control provides inadequate system responsiveness and behavior discrimination. Each is limited in its ability to convey the will of the user to operate the device to which it is attached. Trade-offs are frequently involved in their design and use.

**SIGNIFICANCE:** Successful development of a device which can overcome current interface shortcomings would be of significant value to severely injured individuals who wish to control their mobility or communication in a socially acceptable and aesthetically pleasing manner. Desired characteristics would be operation of a device from a distance, without the necessity of mechanical contact; use of a part of the body that will not interfere with sensory input; and easy training and use. Other features such as modular construction, low cost, the ability to accommodate many users, and self-calibration would contribute to the appeal of the interface, and thereby stimulate its widespread use.

**BACKGROUND:** Several methods have been developed to allow a user to communicate his/her will to the device he/she wishes to control. Demonstrated techniques include: magnetic induction coils, light emitter / detector pairs, radio transmission, EMG signal detection, EEG signal detection, eye movement detectors, and light reflectance. While the feasibility of each has been demonstrated, each approach fails one or more of the performance criteria defined above. Inherent to many of these potential solutions is the requirement that the user to wear a portion of the interface.

**HYPOTHESIS:** Ultrasonic distance ranging requires no physical contact with the object of interest. A person would not feel encumbered using a device which incorporates this technology. The investigators hypothesize that an array of distance ranging sensors can monitor the head position of a severely disabled quadriplegic operator to obtain command and control information for the operation of mobility and communication devices.

**APPROACH:** In this project, two Polaroid ultrasonic distance ranging sensors are employed. They emit inaudible sound waves which propagate through the air until reflected by an object. A portion of the echo signal returns to the transmitting sensor and is detected by the associated electronics. The measured time from transmission to the reception of the echo is proportional to twice the distance between the sensor and the object. In this rehabilitation application, two separate sensors are directed at the user's head. The two distance ranges, one from each sensor to the head, and the fixed separation of the sensors describe a triangle whose vertices are the two stationary sensors and the user's moving head. A geometric relationship allows the offset from the base line and center line of the two sensors to be calculated. This information is then used to map the user's head position onto a two dimensional control space.

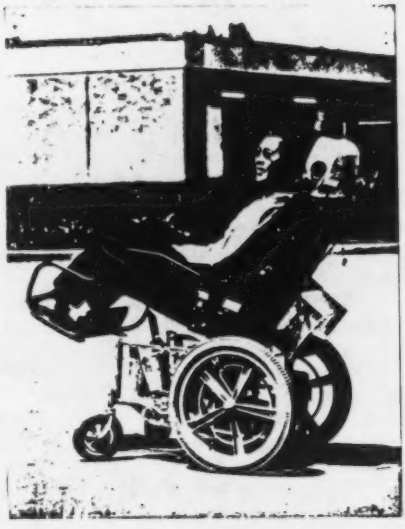

Figure 1. UHCU equipped wheelchair. The sensors are mounted outboard of the headrest.

In operation, users of the Ultrasonic Head Control Unit (UHCU) merely tilt their head off the vertical axis in the forward/backward or left/right directions. Their changing head positions produce the same effects as a joystick. Thus the UCHU can be used to control any device usually controlled by a joystick (wheelchair, communication aid, video game, etc.).

The main advantage of this type of interface is that no mechanical contact between the sensors and user's head is required. This effectively separates the user from the device being controlled. With this unit, users should not feel confined by devices around their face or body, as frequently occurs with other interfaces. The use of the remote sensing ability of the UHCU should result in rehabilitation devices that are socially acceptable and cosmetically pleasing

**STATUS:** UHCU's have been installed on two electric wheelchairs. The first is an E&J Model 3P equipped with a reclining Recaro seat and is in use in France by a quadriplegic woman. The second is mounted on an Invacare Rolls IV with a Solo Products Power Pack and is being evaluated by Spinal Cord Injury patients at the VA facility.

Both units have been operational since June, 1983. After a short demonstration and training session, quadriplegic users were transferred into the chair and were able to successfully navigate the chair without a problem. Users state that they preferred the ultrasonic head control to the chin-controlled joystick wheelchairs.

Several other applications of the UHCU are being pursued. Used in conjunction with a robotic arm, the UHCU will provide control of the robot's hand position. The user's head position will be used to control two degrees of robotic arm freedom. Compared to the current voice recognition method, a faster and more interactive manipulation of the hand is anticipated.

In a communications application, the UHCU will monitor the user's head position and control a moving light cursor in an X-Y matrix of letters and words. Selection is then accomplished by pausing on the desired square. A commercial joystick operated aid has been donated for this work.

A technical manual documenting the work on the UHCU, including background material, electronic schematics, computer program listings, explanations, and illustrations has been compiled. Its intended purpose is to provide information that would allow a technically knowledgable and

adequately equipped person to construct a UHCU and apply it to the control of devices such as powered wheelchairs. This manual has been made available to interested parties who are considering the UHCU for research or commercialization.

International Texas Industries (Intex), of San Antonio, Texas has made initial committments in pursuit of production of a wheelchair controlled by the UHCU. They anticipate the first units will be ready by the end of 1984.

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Project support: RR&D base resources and funds
Paralyzed Veterans of America grant
Donations from Invacare, Solo Products, Jib Ray
Technical support and donations from Polaroid, Inc.
October 1981 to present

## REHABILITATION INFORMATION PROJECT


| | |
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**PROBLEM:** The rehabilitation community with its numerous members, their varied professions and abilities, and geographic dispersion has developed its own special needs. One broad issue concerns information exchange, in particular the need for increased intra-community communication and consumer involvement. As important as these needs may be, the current means of accomplishing them appear inadequate, as the literature suggests. Without such continued communication, informationally isolated islands of community members persist. As a result, research activities and funding are often duplicated, new techniques and devices are not widely disseminated, the experiences of members are not communicated, and users of aids do not have a voice in their development.

**SIGNIFICANCE:** An ideal solution to this situation is a mechanism that enables rehabilitation community members to make informed decisions based upon an enhanced ability to interact in an effective and synergistic manner. If such a mechanism existed, the barriers that distance, schedule, finances, ability, and possession of equipment impose on information access would be reduced, permitting wider participation by all. However, such a solution does not now exist.

**BACKGROUND:** The RR&D Center and Western Blind Rehabilitation Center (WBRC) have cooperated on numerous projects during the past several years. These projects include a joint VA/Stanford project to develop a personal information system for the visually impaired. Preliminary work conducted at the RR&D Center has demonstrated the feasibility of a universally accessible information system serving the rehabilitation community. The WBRC has operated the Electronic TeleCommunications, Education, Training, Evaluation, and Research Activity (ETCETERA) and more recently the Computer Training and Education Program (C-TEP) which provides a community locus for training and research on computer-based aids for the visually impaired. Other local resources, including the Sensory Aids Foundation, provide a vocational setting for the practical application of this training. While other systems such as Abledata, Special Net, Wellnet, and Handicapped Education Exchange offer information in computer form, they all require the use of a modem and terminal or computer. A system that requires no special equipment for access, provides interaction between users, is easy to learn and use, and is equally suited for all those interested in rehabilitation issues would promote a significant improvement in information dissemination and informed decision making.

**HYPOTHESIS:** It is hypothesized that a computer-based information system accessible by Touch-Tone input and machine produced synthetic speech can be developed and employed within the local rehabilitation community to foster increased information exchange and consumer involvement. The system's specific goals are to: improve employment opportunities, reduce social and economic dependence, improve information dissemination, and improve communication between rehabilitation researchers.

**APPROACH:** The goal of this project is to develop a universally accessible mechanism. Its potential users are both agencies and individuals. Federal and private organizations such as the Veterans Administration (RR&D and WBRC Centers) and Sensory Aids Foundation will be involved initially. Individual participants include those with disabilities, physicians, manufacturers, therapists, policy makers, employers, those seeking employment, educators, and senior citizens.

The information in this system is to reside in a telephone accessible central storehouse from which users select a specific subset for decision–making, evaluation, interaction, inquiry, or response processes. For example, one would be able to make a purchase decision between one of several functionally identical devices based upon the centrally held documented experiences of others.

The central system manages data, converts selected information to synthetic speech, and transmits it over the telephone. The user's Touch–Tone keypad provides unrestricted interactive input. In operation, one telephones the system and responds to a series of spoken prompts with Touch–Tone button presses. The system decodes these keystrokes and selects information to be *spoken* from its store. Messages can be sent to the system by employing a two–button entry scheme. In this manner, both information retrieval and generation can be performed by users without their purchasing specialized equipment. Terminal and modem communication is also supported to accomodate those with impaired hearing. A human information specialist is employed to aid new users and provide advanced assistance for others.

To achieve enhanced communication, several methods of information exchange within the system will exist. On–line newsletters will facilitate the dissemination of information from a central organization to its members. Separate publications would be created to cater to the interests of the spinal cord injured, visually impaired, and those desirous of data on vocational aids. An electronic employment service will also be implemented, acting as an information node between prospective employees, potential employers, and an employment counselor. A continuing advertising section on the system would provide users with an up–to–date list of jobs available and situations wanted. Interviews could be conducted and resumes exchanged in privacy over the proposed system. Finally, Design Circles will allow consumers to interact with designers at all stages of development of new products. *Meetings* of the group could also include both consumers, potential manufacturers, and health care professionals.

Although this one system cannot possibly serve the entire national rehabilitation community, it can serve as a local model for other identical microcomputer–based systems or a national network connected to a larger computer.

**STATUS:** Several speech synthesizers have been acquired and their characteristics have been investigated. Microcomputer hardware systems have been surveyed for their suitablility for this project and a database software search has begun. While the need and problem have been determined, a concerted effort on this project awaits funding. A proposal requesting funding for this project has been submitted for VA merit review. If approved, the two year project would receive initial funding October, 1984. At that time, the processes of equipment acquisition, design, development, testing, and evaluation will begin in earnest. One year will be required before actual system operation will commence. An evaluation of the usefulness of the system will be made at the end of the second year. If successful, additional funding will be requested for system replication in other areas of the country and for inter–system linkages.

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Project support: RR&D Base resources and funds

# INTERACTIVE VIDEO EDUCATION SYSTEM FOR REHABILITATION


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|---|---|
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| INDER PERKASH, M.D. | Co-principal investigator, VA |
| LARRY LEIFER, Ph.D. | Co-investigator, VA and Stanford |
| JOHN TANG, M.S. | Biomedical engineer, VA |
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**PROBLEM:** In order to facilitate a return to active and fulfilling lives, spinal cord injured patients, and those associated with their care, need to learn a wealth of information. Rehabilitation is largely an educational process where routine issues in life are re-examined and new approaches learned. Information about activities of daily living, vocational opportunities, and recreation are just a few of the important concerns of an effective rehabilitation program. This information should be available to disabled users so that they can independently access it when they need it or are ready to learn it.

Ideally, a rehabilitation program should be flexible enough to accommodate the variety of needs and learning rates among the patients. Such flexibility could also allow individuals to govern their own pace through the rehabilitation process, further encouraging their independence and personal initiative. For the physically disabled, however, their ability to interact with conventional educational aids may be impaired. This constraint indicates the need for an interface which brings the material within their range of perceptual and motor abilities. This interface needs to be incorporated into a system that effectively presents the educational information to the user population.

**SIGNIFICANCE:** This system promises to be cost effective while providing greater access to information. Successful learning is an experience in which one gains information and an enhanced sense of ability to deal with new situations. A spinal cord injury rehabilitation program using this system could provide patients with information, a model for coping with new situations, and the positive experience of living independently through learning. This system also has potential applications in educational and industrial training environments.

**BACKGROUND:** Classroom instruction and one-on-one sessions with the health care staff are the traditional rehabilitation learning experiences in a spinal cord injury unit. However, limitations of time, facilities, and personnel may make needed information and instruction unavailable just when the patient is most ready to learn. Video is a convenient and effective medium for instructional rehabilitation that is currently widely used. However, many disabled patients are unable to independently operate video playback equipment, placing them in a position of dependence on the health care staff. The need to address this problem was initially identified by a clinical nurse specialist in the Spinal Cord Injury Center (SCIC). The development effort in this project has involved RR&D, SCIC and graduate mechanical engineering students at Stanford.

**HYPOTHESIS:** We hypothesize that a combination of interactive video technology and computer aided instruction methods can be used to supplement and enhance the learning experience of the patients in a rehabilitation program. Further, we believe that the rehabilitation process is significantly augmented by giving patients the opportunity for independent self-instruction and the use of sophisticated assistive aids which encourage independence.

**APPROACH:** Our objective is to provide the disabled community with 24-hour independent access to video information. This involves identifying and consolidating relevant video

educational material and enabling all users to interact with this information resource. The user population includes high level quadriplegics, who have no use of their hands but normal head and vocal control. Able-bodied users, such as family members and health care staff, should also be able to interact naturally with the system. The system will be concurrently developed and evaluated in order to design it to best serve the needs of its users.

**STATUS:** A prototype system has been constructed to demonstrate the concept and undergo preliminary evaluation. A photograph of this prototype in use is shown in Figure 1. In order to make the system accessible to persons with high level spinal cord injuries, it is designed to be automatically activated by the approach of a user. Voice input is used, since disabled and able-bodied users can operate this interface with equal ease. The system is designed to be functionally flexible and easily reprogrammable, allowing us to modify, add, and experiment with different features. It also monitors its own use and stores pertinent data. For example, for each learning session, the computer records the date and time that the system is activated, elapsed time spent with the system, sequence of video programs viewed, and performance characteristics of the voice interface. This information provides a quantitative measure of how the system is performing and being used and will help us better understand the needs of the users. The system is assembled in a self-contained package that can be readily transported to different sites for demonstration and clinical evaluation.

**Figure 1. Prototype Learning Lab in use.**

We plan to continue to evaluate and develop this prototype system. Information gathered from the evaluation of this prototype will be used to design a more comprehensive system. This system might incorporate interactive videodisc technology to provide faster access to more video material. We plan to add more interfaces (joystick, touch screen, etc.) in order to allow users to choose the most efficient mode of input for them. Providing this selection of interfaces would also enable us to compare and evaluate their performance. We also hope to include new interactive video programs which would be relevant to the needs of the users.

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Project support: RR&D base resources and funds
VA Merit Review funds
January 1982 through September 1984

# VISUAL COMMUNICATION LABORATORY
## For The Study Of Graphic Aids

FRED H. LAKIN, M.F.A. — Principal investigator, VA
JEANNE FRYER, Ph.D. — Co-investigator, Clinical Director, Bay Area Head Injury Recovery Center, Berkeley, CA

**PROBLEM:** Aphasics and other persons with linguistic cognitive disabilities have difficulty in understanding and/or using spoken or written language. Yet they can often learn to communicate using appropriately designed graphic communication systems. More scientific knowledge is needed about the development of graphic rehabilitation and communication aids for the cognitively disabled. The Visual Communication Laboratory would provide an integrated set of computerized research tools for investigating the basic phenomenon of visual communication in non-oral communicators. Research results could be applied to guide design of the systems for aiding such communicators.

**SIGNIFICANCE:** Computerized graphic communication systems have great potential value for the linguistic-cognitively disabled. Such systems: (1) can be both rehabilitative and prosthetic, and (2) can increase the effectiveness of a therapist while reducing his/her time involvement.

The extensive monitoring which takes place in the Lab will result in more understanding about both the pictorics of the cognitively disabled in general and each individual user in particular. In the short term, this knowledge will then be used to improve the assistance supplied by the "trainer" programs themselves; in the long term, knowledge gained through the Visual Communication Lab research will guide the design of inexpensive rehabilitative computer graphics systems for use in clinic and home.

**BACKGROUND:** Cognitive rehabilitation, visual communication systems, and computer graphics have thus far not been integrated into a single research system. The PAM computer graphics system [Lakin 1980] offers good potential for unification of these capabilities.

In other work, cognitive rehabilitation has seen standard video games used for disabled clients [Lynch 1982]. Specialized computer programs have been written for cognitive retraining [Gianutsos 1980]. In electronic communication aids, visual "communication boards" linked with microcomputer screens are beginning to appear [Prentke 1982]. The LOGO computer environment has been used for diagnostic and theraputic purposes for cerebral palsy adolescents [Weir 1981], but text is still the primary interaction mode. A non-computer visual communication system utilizing 3x5 cards was taught to aphasic patients "... *who possessed little or no ability to communicate using natural language* ..." [Baker 1975, Gardner 1976]. The researchers concluded that "*The evidence suggests that some severely aphasic patients can master the basics of an alternative symbol system*".

**HYPOTHESIS:** The overall hypothesis of the Visual Communication Laboratory project is that graphic communication rehabilitation of the linguistically cognitively disabled is an important phenomenon, and that it can be fruitfully studied in a research lab based on a system of computer graphics software. The Lab offers a variety of research tools for studying graphic communication and its development. These tools are all integrated within the lab software system.

This hypothesis breaks down into four parts:

1. Visual marking skills are a behavior which can be learned through training on a computer graphics system.

2. Simple marking and patterning skills can be the basis for using graphic communication systems.
3. Patients' use of graphic communication systems within the integrated Lab will allow a variety of measurement tools to monitor their activity.
4. Measurement of graphic communication activity will assist both the therapist in immediate rehabilitation, and the researcher in studying the principles of graphic aids.

**APPROACH:** The objective of the Visual Communication Lab is to provide clinical researchers with a tool for exploring the role of graphics in the problem solving and communication of the cognitively disabled. This objective will be achieved when the prototype Lab can support and monitor the full process of patient rehabilitation, all the way from initial cognitive assessment to training in a selected graphic communication system (see figure 1.).

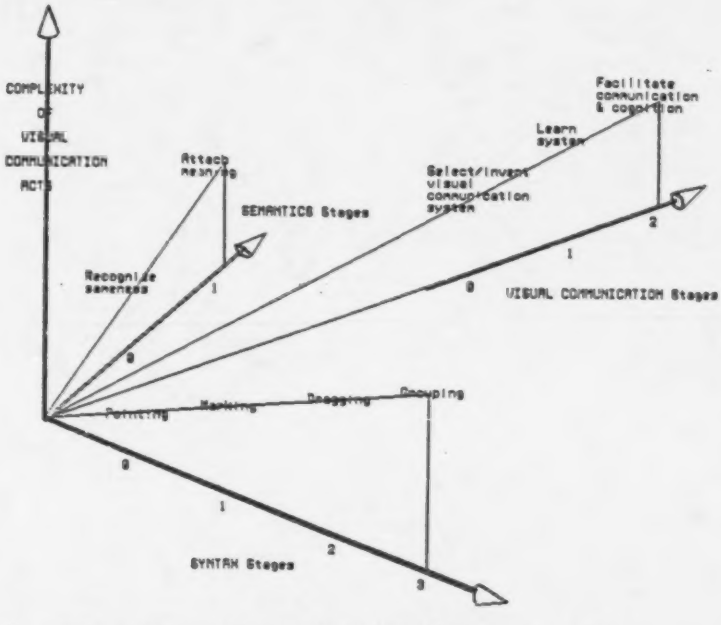


Figure 1. Conceptual framework of the Visual Communication Lab

The focus of the Lab is a visual computer display. Software modules called "trainers" help the clinician to administer training so that the patient can learn to operate the display. Each "trainer" keeps track of patient progress in its domain, and use of this data allows the clinician to select an appropriate graphic communication system for the patient. The basic visual skills acquired through Lab training are general enough to support any of the graphic communication systems currently used by the cognitively impaired, including Bliss symbols, Yerkes lexigrams, VIC symbols, and picture/word matrices.

**STATUS:** A prototype implementation of the Visual Communication Lab, based on the PAM graphics system, has been programmed in LISP on a Symbolics 3600 professional

workstation. Use of this machine was borrowed for one year in order to demonstrate project feasibility. Figure 1 is a screen image from the demonstration prototype. The next step in the project is clinical testing: selection of appropriate patients and training them for graphic communication within the Lab system.

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Project support: RR&D base resources and funds
March 1981 through present

# ARM–POWERED BICYCLE FOR THE DISABLED


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| LARRY LEIFER, Ph.D., | Co-investigator, VA and Stanford |
| PETER AXELSON, M.S., | Co-investigator, VA |
| RONALD GAINES, M.D., | Medical advisor, VA |
| FRANKLIN WONG, M.D., | Medical advisor, Sacred Heart Hospital, Eugene, Oregon |


**PROBLEM:** Individuals without the use of their legs have been excluded from participation in many recreational activities due to the lack of devices matched to their needs.

**SIGNIFICANCE:** Once the basic living needs are attended to, mobility and recreation become paramount to the complete rehabilitation and social integration of an individual with a lower limb disability. Whether for recreation, sport or self-powered transportation, bicycling is a popular activity providing many physical, psychological and social benefits. The availability of an arm-powered bicycle provides individuals with lower limb disability the opportunity to participate in a popular recreational activity and experience the freedom, exhilaration and accomplishment of being on two wheels.

**BACKGROUND:** Arm-powered tricycles have been around for at least 50 years. Currently, several companies market tricycles for children and adults, including an attachment which converts a wheelchair into a tricycle.

The development of the first arm-powered bicycle for disabled individuals began as a VA sponsored student project in the Stanford University Mechanical Engineering Design Division. Four successive prototypes have been developed.

The arm–powered bicycle features adjustable side casters which smoothly touch down at the desired lean. The side casters may also be fastened down for four wheel maneuverability indoors. A folding crank tower has been included for easier transfer to and from wheelchairs.

**HYPOTHESIS:** The technology to develop an arm-powered bicycle with features matched to the special needs of the disabled is now available due to advances in our understanding of human-powered vehicle design, seating strategies, and the ergonomics of control specific to disabled individuals.

**APPROACH:** The development approach has been to design, build and test successive prototypes incorporating improvements, evaluating alternative configurations, and enhancing the manufacturability of the design.

**STATUS:** The fourth version of the arm-powered bicycle, a pre-production prototype, was completed by Autumn, 1982. In Spring, 1983, a company called Recreational Mobility, Inc., located near Eugene, Oregon, began production of the arm-powered bicycle. Calling it the Handbike, Recreation Mobility has built and marketed three versions, including a standard adult version, a child's version and a touring/racing version.



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Figure 1. Handbike

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Project support: RR&D base resources and funds
Telephone Pioneers of America
University of British Columbia Athletic Department
British Columbia Program for the International Year of the Disabled Person
Stanford University Mechanical Engineering Design Division
October 1979 to April 1983

# ARM-POWERED TANDEM FOR DISABLED AND ABLE-BODIED TO RIDE TOGETHER


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| LARRY LEIFER, Ph.D. | Co-investigator, VA and Stanford |
| PETER AXELSON, M.S. | Co-investigator, VA |
| RONALD GAINES, M.D. | Medical advisor, VA |
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**PROBLEM:** Individuals with lower limb disability who endeavor to live healthy and meaningful lives may benefit greatly in their physical, psychological and social well-being from participation in active recreation with family and friends. A tandem bicycle to be shared by individuals with and without disability will literally provide a vehicle for integrated mobility and recreation.

Although a tandem bicycle for disabled and able-bodied to ride together is a simple concept, it does not yet exist as a product. Alternative design configurations need to be developed as prototypes and the most desirable design manufactured and marketed.

**SIGNIFICANCE:** The availability of a tandem bicycle for able-bodied and disabled to share will provide an important recreational alternative promoting participation and social integration. The riders will move as one, controlling the bicycle's balance and powering according to their individual abilities.

**BACKGROUND:** The development of a single rider arm-powered bicycle, the *Handbike*, is essentially complete. A manufacturer has begun initial production and several versions are now available.

As a spin-off from the develoment of the *Handbike*, the first prototype of the *Handbike* tandem for disabled and able-bodied riders to share, was completed in June, 1983. Conceptually, the configuration of the tandem consists of merging the *Handbike* in the front with a standard bicycle in the back. In the interest of independence and equality, the first prototype of the tandem was designed to also be ridden by one rider alone in either the front or back position.

**HYPOTHESIS:** The experience needed to design, build and test a tandem bicycle with an appropriate arm-powered rider position follows directly from the development of the single rider arm-powered bicycle.

**APPROACH:** An alternative drive system is planned for the front rider position on the second tandem prototype incorporating both arm and leg propulsion. The front rider will have the option of using any functional limb for powering. This front drive system will be interchangeable with an arm-power lever drive system so that the desirability of either configuration may be tested on the same prototype.

**STATUS:** The design of the second tandem prototype is nearing completion and building will soon begin. A subsequent pre-production version of the tandem is expected to draw from the best features of the first two prototypes.

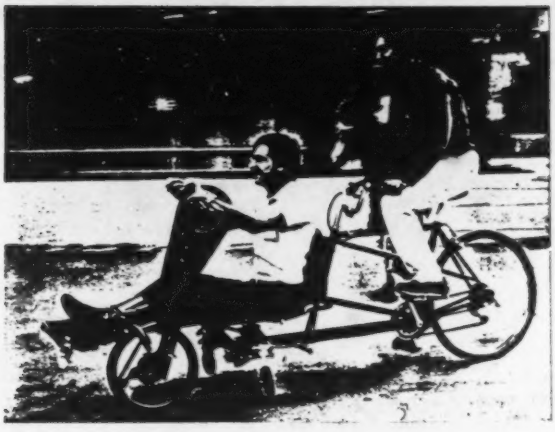

Figure 1. Handbike Tandem

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Project support: RR&D base resources and funds
University of British Columbia Athletic Department
British Columbia Program for the International Year of the Disabled Person
January 1982 to June 1984

# AN IMPROVED BACKBOARD FOR CERVICAL SPINE INJURIES


| | |
|---|---|
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| DOUGLAS SCHWANDT, M.S. | Co-investigator, VA |
| CONAL WILMOT, M.D. | Collaborator, Santa Clara Valley Medical Center, San Jose |
| ELMER SPECHT, M.D. | Collaborator, Ralph K. Davies Medical Center, San Francisco |


**PROBLEM:** Existing equipment for moving spinal cord injury patients from the field to the emergency room, and from there to specialized treatment centers is cumbersome, does not provide reliable cervical traction, and is incompatible with computed tomography (CT) scanning diagnosis and hyperbaric oxygen (HBO) treatment equipment.

Both hanging weight and elastic band traction systems result in varying traction loads due to motion or friction. Patients must now be moved off of backboards to CT scanning and HBO chamber platforms. Every time a patient is moved or traction is interrupted, the chances of doing further harm are greatly increased. Specifications for an improved backboard with cervical spine traction must include compatibility with transportation, diagnostic and treatment equipment.

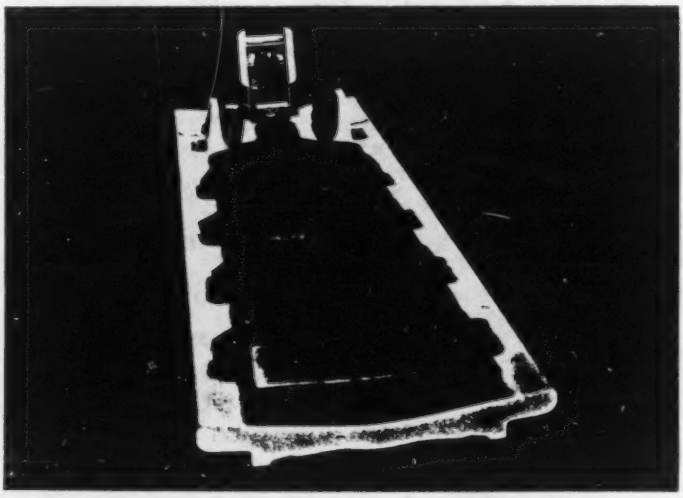

**Figure 1. Second STS prototype.**

**SIGNIFICANCE:** The benefits to be achieved by an enhanced system for stabilization and traction of spinal cord injury patients are profound. The spinal cord may not be completely severed or severed at all, so adequate care after the injury may make the difference between full recovery or paralysis the patient must live with for the rest of his or her life.

**BACKGROUND:** The first prototype of the Stabilization Transport System (STS) was

completed in Summer, 1981, and placed at Santa Clara Valley Medical Center for use and evaluation. The backboard of laminated mahogany construction has a curved cross section to minimize pressure. Attached to the backboard is an adjustable force, constant tension spring traction system.

The second prototype, completed in Summer, 1982, uses a contoured fiberglass shell over a styrofoam core. Attached to this backboard is an alternative configuration for the constant tension spring traction system. Although fiberglass is not sufficiently transparent to x-rays, this prototype was intended as a model leading to future composite construction utilizing the more desirable carbon graphite material.

**HYPOTHESIS:** Careful determination of the numerous and stringent specifications for an improved backboard/traction system, combined with recent advances in composite material construction, will lead to a design consistent with the early medical needs of the spinal cord injured.

**APPROACH:** Development is carried out on a prototype "design, build and test" basis. Close collaboration with local spinal cord injury centers and potential manufacturers helps assure that all steps in the development process will lead directly to a quality product that may significantly improve the early care of the spinal cord injured.

**STATUS:** A report detailing the results of the first two prototypes has recently been completed. Included in this report is an updated survey of the state-of-the-art, a comprehensive list of functional specifications and testing procedures. This report has provided the groundwork for subsequent design improvements. Proposals are being submitted for funding to continue the development of the Stabilization Transport System.

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Project support: RR&D base resources and funds
Ralph K. Davies Medical Center
Santa Clara Valley Medical Center
August 1979 to June 1985 (pending merit review funding)

# INTEGRATED WHEELCHAIR TECHNOLOGY TESTBED


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|---|---|
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| DAVID J. NAPOLITANO, M.S. | Co-investigator, Stanford, VA |
| TIMOTHY PRENTICE | Draftsman, VA |
| JAMES ANDERSON | Modelmaker, VA |
| LARRY TUTTLE | Consultant |


**PROBLEM:** Wheelchairs have traditionally used a relatively narrow range of potentially applicable technologies. Newer technologies (such as synthetic composite structural materials and digital motor control) used in isolation lead to incremental improvements, but are often limited in their potential effectiveness when used in an otherwise conventional configuration. Other issues, such as styling, have not been previously effectively addressed. Wheelchair manufacturers are unable to commit resources to develop designs significantly different from those already tooled and in production.

**SIGNIFICANCE:** Improvements in the mobility of disabled veterans resulting from the use of more sophisticated power wheelchair configurations can improve their ability to access a variety of indoor and outdoor environments, enhancing their integration in society and the economy. New material technologies can yield improved wheelchair durability and convenience, as well as lowered purchase cost, while more attractive styling can ease social integration.

**BACKGROUND:** The RR&D Omnichair project resulted in a "proof of concept" vehicle that is capable of moving forwards and backwards, directly sideways without turning, turning in place, or any combination of simultaneous motions. This novel mobility device became the object of a variety of industrial design studies by interested professionals and students. A graduate student project group developed a programmable digital controller for the Omnichair at Stanford in 1982. It was desired to integrate the experiential results of this work in a working wheelchair technology testbed.

**APPROACH:** It was decided that RR&D would undertake the design and fabrication of a wheelchair technology testbed that would embody a variety of new technologies used to their best advantage. The technologies targeted included synthetic composite materials, power MOSFET electronics, nickel–cadmium batteries, and microprocessor–based digital control electronics. It was further intended that the resulting design would also represent the state of the art in reliability, ease of manufacture, and ease of owner servicing.

The costs involved in building this device were born by a combination of Base funds (for chassis and mechanical constructions), Merit Review funds (digital feedback controller and power electronics) and industrial cooperation (seating system, motors, and assorted components). The expertise of a large number of center personnel from all three organizational groups was recruited to assist in programming, physical modelling for design of the composite components, styling conceptualization and housing realization, and team support. The physical vehicle was completed in early June in time for the annual meeting of the Rehabilitation Engineering Society of North America, though it was not operational due to software development problems. The vehicle, nicknamed "Alexis" by the development team, was functionally complete in August.

**STATUS:** Substantial industrial interest was generated by the development and completion of this vehicle, and in September of 1983, a venture capital company (International Texas Industries) signed a licensing agreement with the holder of the omnidirectional drive patent.

The Alexis is now in an industrial design phase and is expected to be in production by the end of calendar 1984. Work on the vehicle prototype ceased at RR&D upon consummation of the patent agreement. The technologies and designs developed for the prototype (power electronics, digital controller and proportional-integral feedback algorithms, synthetic composite chassis/suspension) are freely available to any interested parties.

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Project support: Merit Review
Base resources and funds
January 1983 to December 1983

# DEVELOPMENT OF A CAMERA FOR APPLICATION IN SENSORY AIDS FOR THE VISUALLY IMPAIRED


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|---|---|
| RICHARD D. STEELE, Ph.D. | Principal investigator, VA |
| DEAN HENNIES, M.S. | Electrical engineer, VA |
| ROBERT SMITH, M.S. | Biomedical engineer, VA |
| MELVA CHANG, B.S. | Biomedical engineer, VA |
| RAFAEL MIRANDA, M.S. | Electrical engineer, Ames Research Center |
| SALLY L. WOOD, Ph.D. | Assistant Professor, Cornell University |


**PROBLEM:** For both professional and personal reasons, visually disabled people often need direct access to inkprint — that is, without requiring the intervention of a sighted person either as a reader or Braille translator. Devices such as the Optacon and the stereotoner, which attempt to meet these needs by converting letter shapes into identifiable tonal patterns or into non-Braille tactile displays, require in practice considerable skills and training on the part of the user. Speech output readers, such as the Kurzweil Reading Machine, can serve a larger population, but current models are too expensive to be purchased by most visually impaired individuals, and too large and heavy to be transportable if they are acquired. The need, therefore, is for an versatile, affordable and portable reading aid.

**BACKGROUND:** The earliest device to address needs of this sort at all was the Optacon, an optical to tactile converter. This device captured inkprint with a hand-guided camera, and displayed the shapes of the letters on a 6x24 vibrotactile display. When it appeared in the mid 60's, it represented the state of the art in reading aids for blind individual; however, by the mid 70's, it was clear that speech synthesis should allow for the practical development of a voice output reading aid. Telesensory Systems, Inc., the manufacturer of the Optacon, undertook to make such a device by attaching a optical character recognition module to the existing Optacon camera. This "talking Optacon", named officially the Hand Scan 1, was manufactured in a total run of 8 units, to be distributed to various Centers for evaluation. The resultant conclusions suggested that while the time was ripe for a device of this sort, and while the Hand Scan 1 provides dramatic proof of concept for the idea, that nonetheless the existing units were too costly, inconvenient and demanding in their operation to become a practical commercial product. This merit review funded work stems from a proposal to develop a device which eliminates the shortcomings found during the evaluation of the Hand Scan 1.

**APPROACH:** A hand-guided reading aid is being designed and three prototypes are to be constructed. The devices have been designed to be versatile, portable, less expensive than functionally comparable devices, and easy to use. This reading aid will capture inkprint images via a small, hand-guided camera, capable of reading printed materials over a wide range of type sizes (6 points to 60 points) and styles. The device will use adaptive signal processing techniques to select appropriate thresholds and magnification levels during operation, and will additionally provide the user with feedback to assist in the task of line tracking, while allowing a large tolerance for error in hand tracking. The design will replace complicated mechanics and optics with signal processing techniques. To make the aid versatile in use, it has been designed to interface to a variety of output devices, including speech synthesizers, low-vision magnified letter displays, Optacons, stereotoners, and commercial personal computers. These options should allow users to configure personalized systems in accordance with their own needs, abilities, preferences and pocketbooks.

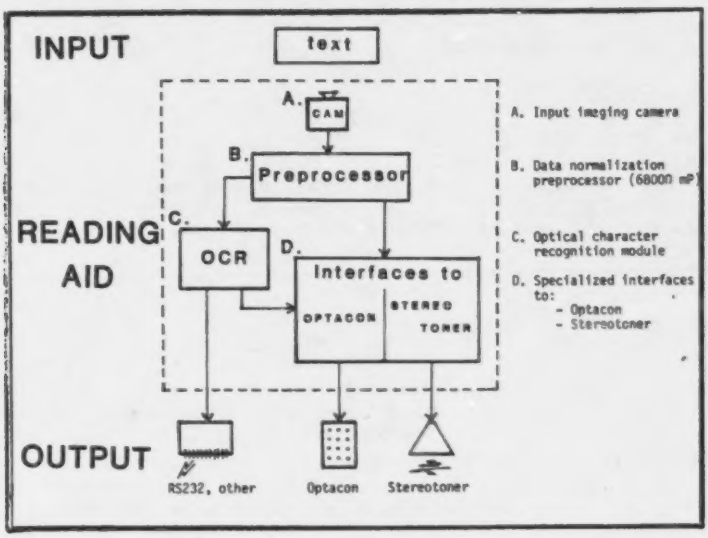


Figure 1. Reading Aid Block Diagram.

**STATUS:** Hardware for most of the major components in the project development stage has been acquired, including the central processors on their printed circuit boards with memory chips, card cages with power supplies, a compiler and cross compiler to allow software development to proceed in a high-level language on the Center's VAX computer. These components are currently configured into an operational development system, enabling software generation and testing to proceed for the final device. Similarly, components for the image input unit are largely on hand, including focussing fiber optic arrays, an optical random access memory (RAM) component, a charge-coupled device (CCD) array, a direct memory access (DMA) board. Work on the design of the image input device is proceeding, with components currently being configured to capture image data for future device development work. Development of the output interfaces is at an advanced stage. The interface board to the Optacon has been completed and interfaced to the 68000 microprocessor, allowing that output device to run under our device's microprocessor control. A stereotoner that attaches to the Optacon is operational as well. Much of the initial software to allow the image processing has been written, tested on the VAX and cross-compiled for running on the 68000 microprocessor. ASCII output ports for communicating with other microprocessors are available directly on the 68000 boards; the generation of ASCII code from the input data stream awaits the development of the optical character recognition module, which is an object of current development efforts. Work in progress focusses on completing the design and building a prototype image input device, developing the software to incorporate into the image pre-processor (to handle adaptively thresholding, magnification, textual line finding and character finding), and the optical character recognition module.

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Project support: RR&D base resources and funds
VA Merit Review funds
Cctober 1981 through September 1984

# DEVELOPMENT OF A MICROPROCESSOR-BASED, REAL TIME SPEECH CAPTIONER FOR THE HEARING IMPAIRED

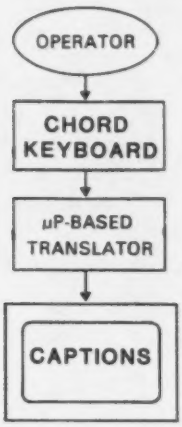
RICHARD D. STEELE, Ph.D. — Principal investigator, VA
MELVA CHANG, B.S. — Biomedical Engineer, VA

**PROBLEM:** Many deaf individuals, particularly those who fall subject to hearing impairments after reaching full maturity, never become completely adept at either sign language or at "lip reading". Such people would be able best to assimilate what another is saying if it were displayed, as it is spoken, in written English. A device which allows such "captions" on another's speech to be produced in real time may be called a speech captioner, and the development of one with low costs, efficient real-time operation, and properly spelled English output is the goal of this project.

**BACKGROUND:** The first microprocessor-based, real-time speech captioner was developed at Southampton University in England around 1978. It used a Palantype chord-keyboard input interface, which is similar to the American stenotype keyboard, but with a few more keys and a slightly different keyboard arrangement. It was operated by a hearing palantypist, who recorded what another was saying, just as a court reporter takes down a verbatim transcript of testimony in court. The microprocessor received the stream of chords, which represent phonetic syllables interspersed with chords representing punctuation marks and conventional abbreviations, and mapped it into output "sentences" of English words interspersed with phonetic syllables. In 1980, the British did the first live captioning on television, and since October 1982, several American televisions have installed similar systems built around the stenotype input interface. All of these systems work fairly well, but have two important drawbacks: first, they are expensive (tens of thousands of dollars apiece), and second, their output disintegrates from English into incomprehensible gibberish periodically. A device which is inexpensive, works at conversational speeds, and produces reliably high-quality text output will represent an important improvement over current devices.

**APPROACH:** The problems of high cost and periodic text disintegration are interrelated: the traditional stenotype keyboard produces output which requires a great deal of computing power to map into proper English, and the process is fragile, in that a single error can cause entire series of syllables to be misinterpreted. What is needed is an alternative approach, one which combines the speed of the stenotype keyboard with the spelling orientation of standard typewriter keyboard output. A device called the stenokey, constructed by the Bulgarians, suggests ways to achieve this goal. Their approach is simple but sensible: stenokey allows the operator to depress several keys at a time, the primary source of speed on the traditional stenotype machine, but they require that the chosen keys represent actual letters of the word (rather than phonemes in a phonetic syllable). The operator, using several thumb keys, also gives the device "instructions" as to how those letters are to be arranged on the page. The microprocessor then has the very simple task of placing items on a page according to a fully specified sequence. The result is a device which has been demonstrated to be operable at conversational rates; it can produce properly spelled, clean text transcript of another's words virtually as the other speaks. However, being built initially for operation on Bulgarian, the device is not well suited to the English language, either from the point of view of its overall design, or from the perspective of its operational features.

# SPEECH CAPTIONER




System characteristics:

1. Portable
2. Inexpensive
3. **Properly spelled output**
4. Future rehabilitation application

Figure 1. Speech Captioner Block Diagram.

**STATUS:** Three questions are being addressed in the current investigations. First, how do the stenotype and the stenokey chord keyboards compare with one another for efficiency and quality of English language output; second, what are the shortcomings of the stenokey device for handling English language output; and third, what general principles may be extracted from a study of the two keyboards to contribute to the development of a third, improved keyboard with that draws on the strengths of the other two? In initial work on this project, an interface module was built for the standard stenotype keyboard. This interface module allows a host computer to receive, in efficient form, information about what chords are struck, when they are struck, and for how long. This information can be used to characterize the operational characteristics of the standard stenotype keyboard. More recently, the principal investigator inspected the Bulgarian stenokey device during a three–day U.S. display in August 1983; at that time, he was able to speak with some Bulgarian representatives for the device, and with two Americans who had trained on them for three months in Sofia. He was also given the opportunity of operating the device for several hours. From that came a report on the operational features of the machine, and an analysis of its strengths and weaknesses for generating English output. Work is now in progress to characterize the keying demands which each device puts on the operator in recording English text, and to establish which desirable features for that task were overlooked by the Bulgarians in their

demonstrated implementation. Through such work, design improvements for a new interface are being identified.

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Project support: RR&D base resources and funds
October 1982 through September 1984

# EVALUATION OF THE HUMAN/MACHINE/ENVIRONMENT TRIAD: AN INTERACTIVE MODEL APPLIED TO THE ROBOTICS AID PROJECT


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|---|---|
| K.G. ENGELHARDT, A.B., B.A. | Principal investigator, VA |
| INDER PERKASH, M.D. | Principal investigator, VA and Stanford |
| LARRY J. LEIFER, Ph.D. | Principal investigator, VA and Stanford |
| ROGER AWAD, M.S. | Research Health Scientist, VA |
| GAYLE CURTIS, M.S. | Biomedical engineer, VA |
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| BRODIE LOCKARD, M.A. | Evaluation specialist, VA |
| MACHIEL VANDERLOOS, Dipl.Engr. | Research associate, Stanford |
| ROGER WICKE, Ph.D. | Biomedical engineer, VA |

Volunteers:

| | |
|---|---|
| Merry Lee Eilers, M.A. | Marcia Hirsh |
| Matt Lehmann, M.S. | Nick Pruneda |
| Don Spaeth, M.A. | Walter Vogel, M.D. |
| Wayne Young | Lillian Wurzel, M.S.W. |


**PROBLEM:** There is a critical need for user evaluation of rehabilitation research and development products at the prototype stage. There are no established protocols for prototype evaluation, nor are sufficient resources being allocated to carry out this crucial facet of the development process. The government regulates safety and efficacy of market-ready products through the FDA, but has no standardized protocols for evaluation of prototypic rehabilitation products. An environment to facilitate user and applied health professionals' input at all stages of the development process is needed to assure that the products generated are useful to people with disabilities. The Office of Technology Assessment's Report, Technology & Handicapped People (1982), concluded that: "*Evaluation is—or should be—an ongoing and integral part of the entire lifecycle ... A coherent, and well-focused program of evaluation is necessary at all levels of technology diffusion and adoption. Such a program does not currently exist in the disability-related technology sector.*" (OTA, 1982) Research must also be conducted to determine what training procedures should be used to introduce people of all ages to new, sometimes sophisticated products.

**SIGNIFICANCE:** "*More than ever before, technology is bridging the gap between physical disabilities and the limitations those disabilities impose—allowing disabled people to become more independent.*" (Baker, 1981) Prototype devices prove the feasibility of an idea. Prototype evaluation helps define its utility. Prior to prototype evaluation, the usefulness of microprocessor based technology can only be hypothesized. Prototype evaluation is critically important to the efficient utilization of scarce research and development resources. User feedback to designers during the development process will result in a prototype better suited to user needs. The social, technical, economic, and psychological implications of new technology can begin to be assessed during the development phases.

**BACKGROUND:** There are often communication gaps when professionals trained in medicine, the social sciences, and engineering attempt to explain their differing approaches to solving a problem. Yet the evaluation of complex interactions between intelligent systems and

intelligent beings demands an attempt at synthesizing the jargon, styles, and research methodologies of these various fields. The rapidly expanding technological advances, and their unexplored human/machine complexities require an interdisciplinary synthesis of medical, social scientific and engineering methodologies in order to properly evaluate this class of sophisticated devices. An underlying premise is that intergenerational interaction will also facilitate the development of higher quality products better suited to the varied needs of all segments of our aging population.

A team composed of individuals from a variety of disciplines has been organized to develop research protocols and a working model for prototype evaluation. An interdisciplinary evaluation effort is imperative for investigation of the desirability and functional utility of advanced assistive devices (such as the robotic aid). The Interactive Evaluation model (Engelhardt, Leifer, et al, 1983) is a tool to facilitate a flexible, ongoing evaluation process. Its primary objective is to provide user input and feedback to the developers of advanced assistive devices for people with disabilities.

New technologies require new approaches for evaluating utility. No single theoretical or applied research focus can answer the multiple questions that need to be asked about a human's interaction with an advanced assistive device. This was the fundamental premise from which the Interactive Evaluation Model was developed. It proposes a unique approach to several research, development, and evaluation issues that have rarely (if ever) been addressed.

**HYPOTHESIS:** The dominant question is, "*how can evaluation of present and emerging technologies be organized to provide consumers, providers, and policy-makers with adequate information?*" (OTA, 1982). The purpose of the model is the following: (a) develop baseline information on performance characteristics of the human/machine interface, (b) provide current feedback to designers and developers, (c) assess the applicability and acceptability of advanced assistive devices, (d) study pertinent psychosocial parameters, (e) generate data on a successful user and successful system profile, (f) determine the most effective user training procedures for each class of assistive devices, and, (g) investigate dissemination issues and barriers to technical transfer. It is hypothesized that an emphasis on simultaneous technical and clinical investigation will help engineers, designers, and evaluators better understand the desirable and appropriate characteristics and performance parameters of both the human and the machine. It is further hypothesized that by using the Interactive Evaluation Model, the products that are produced will be more appropriate for the end-user and, as a result, compliance rates will be improved.

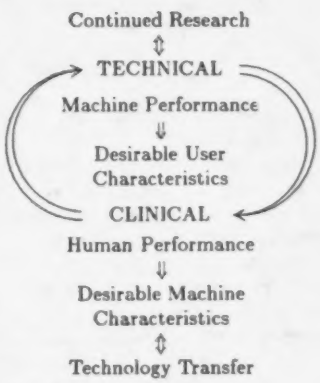


Figure 1. Interactive Evaluation.

The following are the key evaluation questions we are analyzing: (a) Can an increased level of user input produce a more acceptable and appropriate product? (b) Can involvement of users and allied professionals help accelerate the development process? (c) What is the best methodology to use in training a person to control and manipulate state-of-the-art assistive devices, such as a robotic aid? (d) How does prototype evaluation differ from the standard approach to evaluating market-ready products.

The decision process for the evaluation team depends on a group consensus which specifies research problems. The team will focus on questions concerning topics they believe are most important to answer, based on their experience working with users and the system. The problems are further defined by identifying the most appropriate variables and by defining them operationally so that they may be measured from both clinical/social and technical perspectives. The type of

information sought and the sources of available data, as well as conceptual and methodological problems are thoroughly discussed before a strategy for the research study design is initiated. The study design employs multiple measurement techniques.

**STATUS:** This clinical research has generated over 25 professional presentations over the past two years. Abstracts are available in the Robotics Information Package. Over 100 users have been trained to use the robotic aid using the Interactive Evaluation Model approach. They range in age from 5 to 72 years and include over 22 high level spinal cord injury patients. A 200 page manual has been developed and utilized by people of varying levels of formal education, from those without high school degrees to those possessing the Ph.D. Training methods are currently being researched in our Locus of Control study which hypothesizes that successful use of the robotic aid can be enhanced if training style is matched to user characteristics. Voice studies are ongoing to better illuminate the research questions related to using voice as a control mechanism for a sophisticated assistive device. Issues in technology transfer are also being actively examined from the theoretical diffusion of innovation perspective, the health services research perspective, and the manufacturer's production perspective.

Community collaborations:

Palo Alto Senior Center
Peninsula Volunteers' Little House Senior Center
Stanford University Mechanical Engineering Department
Stanford University Communication Department
Stanford University Psychology Department
Children's Hospital at Stanford

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Project support: Merit Review
RR&D base resources and funds
1981 to 1987



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# DEVELOPMENT AND EVALUATION OF A ROBOTIC AID FOR THE SEVERELY DISABLED INDIVIDUAL


| | |
|---|---|
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| JOHN JAMESON, Ph.D. | Candidate, Stanford |
| WALTER CONTI, M.S. | Candidate, Stanford |
| THOMAS BINFORD, Ph.D. | Consultant, Stanford |
| VICTOR SCHEINMAN, Ph.D. | Consultant, Automatix Inc. |


**PROBLEM:** Persons with physical disabilities such as quadriplegia and severe arthritis have a greatly reduced capacity for manipulating their environments, a condition often exacerbated by reduced mobility. The importance of access to, and control of, one's environment has long been recognized by disabled people and rehabilitation professionals. To date the need could only be addressed by human attendants and occasionally by trained animals. We are amongst a small community of researchers who have posed the problem as one of making machines that could be controlled directly by disabled users to effect a functional restoration of their motor skills. We suggest that industrial robotics technology, carefully and sensitively applied, can help bridge the gap between physically limited individuals and their physical environment.

The feasibility of using industrial robotics technology has been demonstrated over the past year in clinical trials of a first generation, general purpose, Robotic Aid prototype. It is now appropriate to commence further technical development based on the results of these studies. The proposed work addresses specific tasks that have been demonstrated to have an important impact on the overall utility of manipulation aids.

**SIGNIFICANCE:** Unlike special-purpose devices and environment controllers, a robotic aid is a general-purpose tool, capable of manipulating a wide variety of objects and performing useful tasks in a changing and unpredictable environment. As a cost-effective alternative and/or adjunct to personal assistance in certain situations, a successful robotic manipulation aid can be expected to enhance the disabled individual's sense of self-worth, functional independence, and productive capacity. There is also an economic incentive to put robots to work for the more than 7000 severely disabled veterans. Their labor-intensive attendant care can exceed $50,000 per year. The total cost of human services in industry averages $17 per hour and is rising. The cost of robots averages $6 per hour and is dropping.

**BACKGROUND:** The application of Robotics to Rehabilitation has few precedents. Over the past two decades, perhaps ten disjoint projects can be found which relate in some way to this human/technology endeavor. Historically, projects have emanated from relatively low technology prosthetics research. At the other extreme, they have been applications of large scale nuclear reactor remote manipulators. Both approaches have tended to neglect the potential for computer-based

control, sensing and decision-making.

More recently, industrial robotics and artificial intelligence have made significant progress in developing utilitarian systems that improve productivity and product quality in a cost-effective manner. While these developments have important implications for rehabilitation, there is a consistent emphasis on excluding humans rather than working with them. Telemanipulation, on the other hand, seeks to produce a mechanical extension of a human being, exploiting the operator's full range of perceptual, intellectual, and especially manipulative abilities.

Between these two extremes, as it pertains to human involvement in the manipulation process, lies INTERACTIVE ROBOTICS, of which Rehabilitative Robotics is a part. The human, exercising a primarily supervisory role, directs the computer system to perform the desired task. A *task* is as simple as directing a *"MOVE LEFT"* action, or as complex as serving a meal. The interactive nature of the process implies that the user has, at all times, complete control of the system. The direction and redirection of all actions serve the operator's plan and intentions. The robot can, and should, do much of the low level detail work required to coordinate its own motion, keep track of obstacles and know something about the objects it is expected to manipulate.

The first-generation VA/Stanford Robotic Aid proved the feasibility of an Interactive Robotic System for disabled individuals. That work began in 1980 (RR&D Merit Review Proposal 49) with a state-of-the-art industrial robot manipulator. The primary task in this initial grant period has been one of system integration (one system for laboratory studies and a second system for clinical studies) and preliminary evaluation by prospective users. Work done up to now with these systems and the clinical exposure we have obtained have confirmed our expectation that a general purpose interactive robotic aid is desired. Work proposed for the future is based on knowledge obtained from these initial studies and is formulated to move forward from a demonstration of feasibility to a demonstration of real utility.

**HYPOTHESIS:** Based on our expectation that the development of a single general-purpose manipulation system is a more cogent answer to the manipulation needs of the severely disabled than is the design of a multitude of special-purpose aids, our current work is directed towards testing the following hypotheses:

> The UTILITY of a robotic aid is primarily dependent on the *user* being able to interact *naturally* with a machine that is capable of performing a variety of generic tasks *autonomously*.
>
> NATURAL human-machine interaction is possible if the interface is managed by *intelligent* programs.
>
> AUTONOMOUS machines must be able to sense their environment, make plans, and control their actions.

**APPROACH:** The VA/SU Robotic Aid was the first project to be based on a commercially available, human-scale, 6-axis, industrial manipulator, driven by high-level software, using totally digital, multi-microprocessor-based control algorithms.

At the time of the development of the first generation system, specific objectives were: 1) to integrate commercially available subsystems, each providing a unique function, into a complete microprocessor-based system; 2) to design a sensate hand to provide the manipulator with tactile sensing for autonomous functions; 3) to create a command language compatible with voice recognition and voice synthesis; 4) to develop algorithms to allow the user to pilot the arm in real time using discrete voice commands and/or analog movements (e.g. joysticks); and 5) to perform a series of clinical evaluations to assure congruence between laboratory objectives and clinical needs.

More recently adopted methods of procedure include: 1) the explicit development of a Dialog Manager to *intelligently* support interaction between the system and the user; 2) the development

of touch, proximity and force sensors to augment the sensate hand and facilitate autonomous task performance by the robotic aid; 3) the inclusion of reflexive functions based on sensor feedback for subtask execution and safety; and, 4) the implementation of interactive instrumentation to record all interactions between the user and the robot and between the robot and the environment.

**STATUS:** The Robotic Aid Project embodies a Clinical System and a Laboratory Development System. The design of the Clinical System has been stabilized to a degree that allows us to pursue intensive evaluation trials with severely disabled individuals at the Palo Alto VA Medical Center's Spinal Cord Injury Service. Over 90 users have been trained to use the Clinical System, of whom more than 20 were quadriplegics. The feedback from this user involvement has driven the development effort and defined specific goals in terms of the most desirable (and feasible) tasks. Actual use has pinpointed areas of needed improvement, including planning and control algorithms, environmental layout, command semantics, command phonetics, and procedures for training new users (an important consideration).

The organizational architecture of the Clinical System is given in Figure 1. The user can directly influence the environment only through the Robotic Aid, while information from the world and the system return through the user's various senses. The Input/Output Processor is the site for most of the system integration, with which this project has been so centrally concerned.

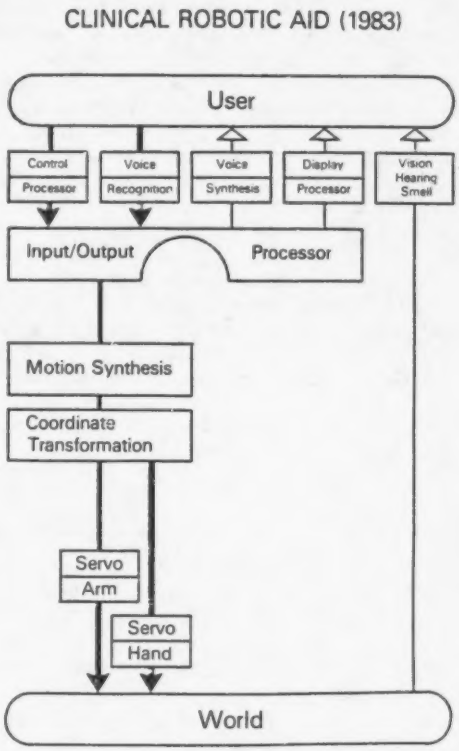


Figure 1. Configuration of the 1983 Clinical Robotic Aid.

The Laboratory System, housed in the Department of Mechanical Engineering at Stanford University, serves as a research tool for developing new hardware, theory, and programs. Specific examples of hardware advances are: 1) the integration of a first-generation sensate hand and the development of closed-loop velocity control based on optical range measuring; 2) the design of a six-axis joystick for velocity control of the arm; 3) calculations leading to the design and implementation of a six-axis wrist force sensor for the robot; 4) design of closed-loop force servoing algorithms; 5) implementation of a second-generation sensate hand, based on the geometry of the first, but with enhanced sensor and electronic componentry; and 5) development and implementation of a unique software control structure capable of integrating all of the asynchronous command and control inputs to the system and assuring safe outputs.

Project support: VA merit review funds
RR&D base resources and funds
1978 thru 1983

# DESIGN OF A SIX-AXIS JOYSTICK FOR A ROBOTIC MANIPULATION AID

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**PROBLEM:** The utility of a Robotic Manipulation Aid depends largely on the interface between the user and the machine. COMMANDING a system to perform a task can be done through keyboard entry or spoken commands, but piloting the mechanical arm is best accomplished by a joystick-like device, or CONTROL INTERFACE, using the motoric capabilities of the user.

A voice commanded and controlled robotic aid for the severely disabled has been developed, and its feasibility proved. The task of providing a general control interface in this context is especially challenging due to the lack of full motor control of the designated system users.

**SIGNIFICANCE:** The goal of the Robotic Aid Project is to develop a manipulation aid for the severely disabled. The utility and success of such an assistive device is dependent on such factors as function, esthetics, safety, and performance. While VOICE is an effective means of commanding tasks, it has been demonstrated that for able-bodied users, it is not the optimal interface for motion control. In fact, performance of the piloting of the arm can be increased by a factor of ten by changing from voice to joystick control. Such a difference makes the development of a control device a high priority for any interactive robot system, but especially for manipulation aids for the disabled.

**BACKGROUND:** Rehabilitative Robotics is a part of the field termed Interactive Robotics, which addresses the problem of developing robot systems under direct user supervision during task execution. It thereby lies between the established fields of Industrial Robotics, whose accent is the elimination of the human operator, and of Telemanipulator Systems, whose mandate is to replicate human motor control in a remote manipulation device. Interactive Robotics seeks to incorporate robot-like capabilities for stereotyped functions and low-level closed-loop control into a telemanipulator system responding at all times to the supervisory control of an operator. The operator must be able to interact on different levels with the process being controlled, and it is recognized that both SYMBOLIC and CONTROL inputs are essential for high performance.

**HYPOTHESIS:** It is our hypothesis that a general joystick-like device allowing control of the robot arm will significantly enhance the performance of the voice-commanded manipulation aid currently in use. The joystick will take over the true piloting functions while freeing the voice communication for supervisory roles.

Further, it is hypothesized that a design allowing simultaneous control of all six axes of the robot will permit the joystick to be a natural interface device, encouraging POINTING in any direction. Such a general pointing capability should be combined with a facility to restrict motion to only ONE axis at a time, thereby eliminating drift in undesired directions.

**APPROACH:** The first phase of the design work involved the implementation of a six-axis joystick prototype for able-bodied users. This stage allows the design of general computer-based strategies of control, verifies the "pointing" hypothesis in the general case of full manipulation capability, and provides a standard by which subsequent prototypes can be judged.

Exploratory work in the first prototype can then guide the design of special-application joysticks and computer algorithms for particular classes of user disabilities. For example, the hand-operated joystick can be used as a basis for the design of a head-operated joystick for a

quadriplegic. For disabilities involving hand tremors or spasticity, appropriate filters and hand restraints can be designed to remove their deleterious effects.

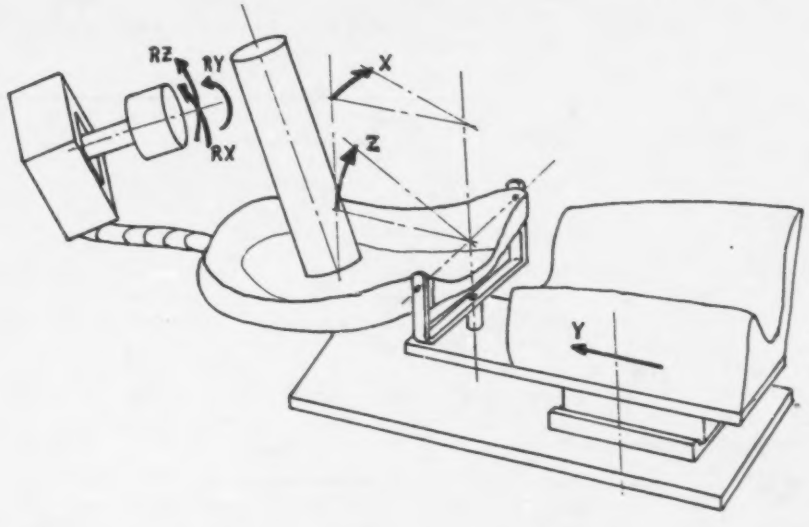


Figure 1. Drawing of 6-axis joystick VIDOF.

**STATUS:** Three prototype versions of VIDOF, the six-axis joystick, have been designed. Figure 1 depicts the third prototype version along with the motions that the joints allow. The cylindrical handgrip is pushed and pulled along with the forearm support, and is twisted right/left and up/down for the primary robot control motions. The small adjustable fingerstick gives control of the secondary motions.

The VIDOF has undergone a preliminary phase of parameter adjustment for able-bodied users. Qualitative feedback from about 20 users indicates that the device requires a training stage before confidence is attained in making complex, high-speed maneuvers of the arm that VIDOF allows.

Future plans include quantitative performance testing, investigating various operating modes, and comparing the range of robot control devices currently available. Finally, the most important goal is extending the design process for the specific need of evolving robot controllers for the disabled users of the VA Robotic Aid.

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Project support: Part of the Robotic Aid Project

# SENSOR AND GRIPPER DEVELOPMENT FOR THE ROBOTIC AID PROJECT


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**PROBLEM:** The utility of any robotic system is limited to a great extent by its ability to sense its environment and to adjust to unforeseen situations it encounters. Three primary goals are obstacle avoidance, object recognition, and force or position ranging feedback during piloting maneuvers. These goals can only be achieved through the extensive use of sensors on or near the extremity of the robot arm, thus the gripper.

Development must thus proceed on three fronts: mechanical design (including gripper mechanisms and transducer technology), electronic interfacing (to preprocess the transduced signals for the main computer), and software algorithms (to make optimal use of the sensor information in the attainment of the goals mentioned above).

**SIGNIFICANCE:** The first generation VA/Stanford Robotic Aid for the Severely Disabled was primarily designed to be a voice-controlled manipulation aid, with the user responsible for all of the decision-making. While feasibility of voice-controlled manipulation was demonstrated, a performance plateau was reached due to the inability of the machine to absorb some of the burden of control. Without gripper-based sensors, the robot's performance and application were consciously limited for reasons of safety, primarily of course for the user, but also for the environment and the robot itself.

**BACKGROUND:** In the interest of safety, performance, and cost-effectiveness, work on gripper-based sensing was begun early in the project (1979). A lack of confidence in proximity sensor technology of five years ago restricted our efforts to the laboratory, where algorithm development and alternate technologies were explored. These exploratory steps were significant: they paved the way for the integration of a new hand for the Robotic Aid second-generation development system that incorporates state-of-the-art sensor and electronic technologies, which we expect to be sufficiently robust for incorporation into the next generation clinical system.

**HYPOTHESIS:** It is postulated that performance of any robotic system can be enhanced by sensory aids. With a robotic system under constant supervision of a user, as is the case for the VA/Stanford Robotic manipulation aid, the user is always in complete control of the arm's motions. For safe and fast action, the limiting factor is the bandwidth of the communication channel between user and system. For some operations, neither voice nor joystick control may be adequate, and feedback from sensors to the system and to the user is the only reasonable means of correction or redirection of movement. Given this postulate, the best location for sensors is the point of interaction between the robot and the environment, i.e., the gripper. Force, touch, and proximity (pre-touch) sensors are deemed to be the most important to implement.

**APPROACH:**

A. Gripper Development. A gripper invented at Stanford University in the context of a Masters Design Project by R. Sun in 1979 served as the basis for three further gripper prototypes. The design is compact yet allows objects of up to four inches wide to be grasped.

B. Optical Sensor Development. It was postulated that optical sensors, due to their size, were a good candidate for proximity sensing. Work is continuing on the implementation of emitter/detector pair sensors. Ultrasonic and tactile (whisker) proximity sensing techniques have also been pursued. These have not been implemented due to a lack of sensor robustness and due to unacceptable package size.

C. Touch Sensor Development. Touch sensing has been explored from two points of view: strain-gaged flexible elements acting as fingernails to the robot hand, and microswitch-actuated plates serving as gripping and touch surfaces.

D. Force Sensor Development. Wrist-located six-axis force sensors have been available in various forms for robot systems for ten years. Until recently, however, none had been developed outside a laboratory, and none had been optimized for the size and force levels of the PUMA-260 type robots.

E. Sensor Signal Conditioning and Preprocessing. In the interests of signal integrity and system modularization, standard signal conditioning electronics were developed and implemented. Single-board microprocessor-based systems were developed to relieve the main system computer from sensor preprocessing, calibration, and initialization chores.

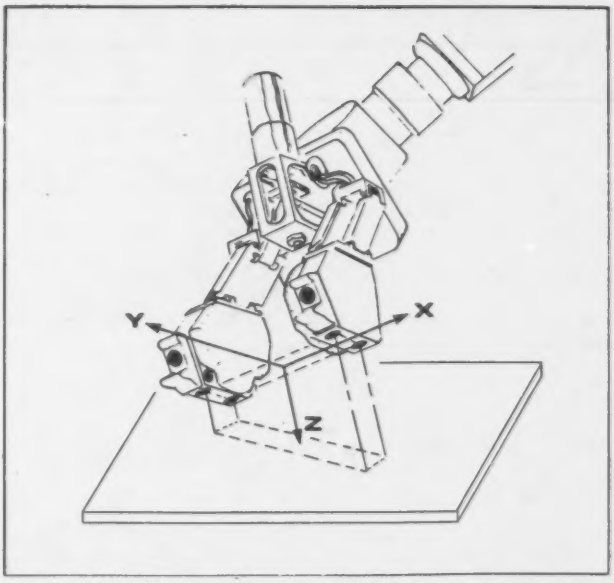


Figure 1. Illustration of the Second Generation Robot Gripper, showing optical sensors and hand-based coordinate axes.

F. Algorithm Development. In order to provide closed-loop control (reflexive functions) based on the sensory input, algorithms based on digital control theory had to be developed and integrated into the main control scheme. These routines provide, for example, motion stops and alarm signals for obstacle avoidance, hovering over a surface from proximity sensing, and strategies for parts-mating tasks like capping a jar.

**STATUS:** An illustration of the second gripper prototype is shown in Figure 1. The hand Cartesian axes are shown. Algorithm development is constrained primarily to this coordinate system since sensor information is dependent on hand movements relative to the world reference frame. The black dots on the finger extremities signify optical sensors. Between the hand and the arm behind it is the location of the six-axis strain-gaged force sensor.

Major categories of gripper, sensor, and algorithm design are given below:

A. Gripper Design. A third-generation gripper has been developed which incorporates several major design enhancements: higher frame rigidity, greater gripping force, better transmission, and less mechanical backlash than previous versions.

B. Optical Sensors. More robust, sensitive and compact optical sensors are being used in the current development system gripper finger pads, permitting more sensors to be used in the same space, and better closed-loop algorithms to be developed.

C. Tactile Sensors. Whisker sensors have been developed to the single-unit prototype stage, but have not been implemented on the gripper.

D. Microswitch sensors. The clinical system gripper has been fitted with microswitch pressure plates on the gripping, forward, and lower touch surfaces for elementary obstacle avoidance and alignment to a surface.

E. Conditioning Electronics and Preprocessor Units. A standardized transducer electronics and preprocessor unit has been developed, allowing any multi-sensor system to be incorporated into the general control scheme with a minimum of specialized interfacing. Both the six-axis force sensor and the new gripper have been interfaced using this procedure.

F. Algorithm development. The design of a real-time control framework in the main computer for the second-generation development system is complete. Work is proceeding on interfacing the gripper control processor and the force-wrist processor to the main computer. Algorithms have been written to implement closed-loop control from these sensor sources, and are currently being tested. Projects include hovering, aligning, peg-in-hole insertions, centering-and-grasping, object contour-following and identification, and obstacle avoidance techniques.

The above elements will be part of the second generation Robotic Aid Development System, presently in its initial stage of full control implementation. The enhancements mentioned will be the first step to endowing the Development System with sensory and manipulation capabilities the first generation Robotic Aid does not have.

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Project support: Merit Review
RR&D base resources and funds
1978 to present

# INTERACTIVE VOICE STUDIES AND THE DESIGN OF COMMAND VOCABULARIES FOR VOICE-CONTROLLED SYSTEMS


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**PROBLEM:** The state of the art in voice recognition technology has made it possible to use voice as a viable communications link to computer systems in some situations. One case in which feasibility has been demonstrated is a voice controlled robotic manipulator system for the severely disabled. Limiting factors of the human/machine interaction center on human performance given machine characteristics and machine performance given human attributes. Errors can result from the incapability of the recognition unit to distinguish between two words with a high level of confidence. Problems also arise from errors that users make in the use or pronunciation of the allowable commands. There is a need, then, to develop tools to construct command vocabularies so that the phonetic differentiability between all words is high, while retaining semantic and syntactic clarity.

**SIGNIFICANCE:** Speech may be one of the only remaining means of communication for people disabled by high-level spinal-cord injury or neurological disorders. This suggests that voice recognition units are potentially very powerful devices for communication with computer systems. The utility of such devices has been demonstrated in the case of the VA/Stanford Robotic Aid Project.

A key component to successful human/machine integration is the voice command recognition rate. If this rate can be increased from the measured overall 85% to the theoretically attainable 99%, then acceptance, performance, ease of use, and confidence are expected to rise accordingly.

**BACKGROUND:** When the first generation of the Robotic Aid System was assembled five years ago, the state of the art in voice recognition technology centered on the digital coding of time-histories of band-pass filtered speech samples. Templates thus created could be stored economically. The Interstate Electronics VOTERM unit was selected because it was one of the better systems of this generation, and because it had extensive diagnostic features.

The voice recognition system cannot monitor or correct its own misrecognitions. A technique was thus developed to systematically tally them manually in order to quantitatively establish the user's as well as the VOTERM's performance during actual use of the Robotic Aid.

A pilot study was conducted using five able-bodied and five quadriplegic users, *prior* to their using the VOTERM as an input device for controlling the robotic aid. Once voice training was completed, most of the users achieved recognition rates of 100%. However, when the same vocabulary was used in the context of controlling the Robotic Aid, frequent recognition errors occurred. It appeared, therefore, that further study was required on variables which affect voice recognition during actual use.

It has been shown that training techniques are crucial to establish user confidence and competence in the operation of a complex system. Special attention, therefore, had to be paid in

the development of voice training techniques, concentrating on speech consistency, user attitudes, stress factors, and environmental variables.

**HYPOTHESIS:** It is postulated that a combination of error tallying, template comparison and user training will remove the most frustrating sources of error for voice control of the Robotic Aid. By coordinating these efforts, a set of vocabulary design/modification tools can be constructed. More importantly, the utility of voice as a viable means of controlling advanced assistive devices such as the Robotic Aid can be assessed.

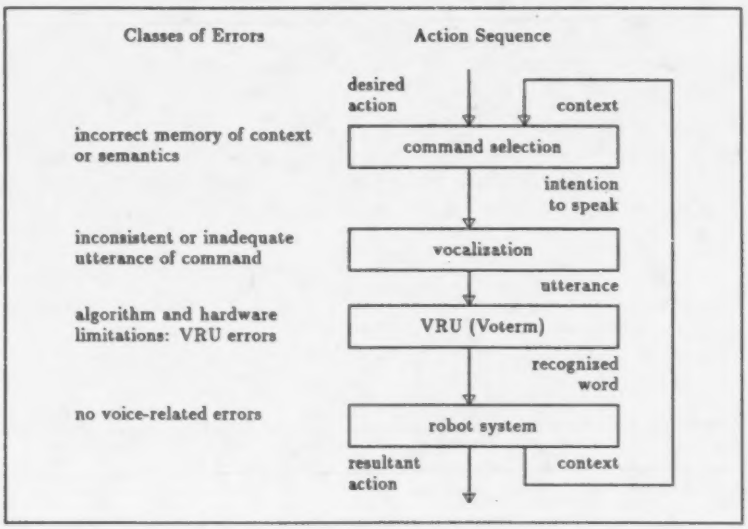


Figure 1. Sources of Voice-related Errors.

**APPROACH:** The general methodology involved the design and development of quantitative analytical tools as well as the evolution of techniques and procedures based on experience and observation of user interaction with the robot system. The following were derived from both technical and clinical assessments in the framework of our Interactive Evaluation Model.

A. The voice command tallying techniques provide information on the commands a robot user employs during a typical one to two hour training session. Information collected includes quantification of: 1) words correctly recognized by the voice recognition unit; 2) words misrecognized by unit; 3) utterances not recognized by the unit; 4) words used out of context by the operator; and 5) invalid words spoken. The first three categories are a measure of the machine's performance, while the last two are a reflection on the user's performance. Figure 1 shows the sequence from user intention to user command to action execution, and the possible areas of command misrecognition.

B. To test prospective command words for compatibility with the existing vocabulary, a computer program (VDELTA) was written to perform template comparisons, indicating differentiability in matrix form. Words too phonetically similar could then be removed from consideration. Figure 2 gives a calibration run of the program on a set of six words that were known to give

problems. One can distinguish a clear separation of the two sets of like-sounding words.

C. Training procedures include specific directives on how to provide the speech quality that the voice recognition unit requires. These guidelines began as the manufacturer's suggestions and evolved to include observations by the trainers on the best techniques and most frequent causes of recognition errors. Factors concerning voice consistency and the emotional content of the spoken commands, i.e., those involving the quality of the interaction between the user and the system, are of prime importance in this context.

| | MOVE | TOOL | WORLD | NEST | YES | LEFT |
|---|---|---|---|---|---|---|
| MOVE | 0 | 39 | 36 | 68 | 63 | 61 |
| TOOL | 45 | 0 | 46 | 69 | 63 | 64 |
| WORLD | 35 | 39 | 0 | 60 | 57 | 57 |
| NEST | 68 | 65 | 61 | 0 | 29 | 47 |
| YES | 74 | 70 | 69 | 45 | 0 | 45 |
| LEFT | 65 | 64 | 62 | 52 | 37 | 0 |

Figure 2. Calibration Run of VDELTA program. Legend: Numbers are differentiability (%) of row word from column word templates.

**STATUS:** The robot command vocabulary currently consists of 58 words, and is in its fourth generation (V-4). The first version V-1 was constructed mainly on the basis of functional capabilities. The subsequent version V-2 was made to incorporate several new command features. No evaluation methodologies were brought to bear at this stage. The evolution from V-2 to V-3, necessitated by user frustration at the quality of the voice recognition, was guided primarily by observations and suggestions by the trainers. Overall recognition rates, as measured by the tally method results, dropped from 84% to 80% overall, due in part to experimentation with 15 new command words. The evolution from V-3 to V-4 was guided by our experience with previous versions, utilizing all of the tools and methodologies mentioned in the preceding section. The overall recognition rate increased from 80% to 86%, with a significant shift to types of errors that less seriously affect performance.

Future plans include special-purpose vocabularies for specific applications and the inclusion of several new functional modes requiring new command words. Based on the success of the previous methods, these changes will be made in a systematic way to optimize user acceptance through careful choice and comparison.

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Project support: Merit Review
RR&D base resources and funds

# DEVELOPMENT AND EVALUATION OF INTERACTIVE TRAINING PROCEDURES FOR THE VOICE-CONTROLLED ROBOTIC AID


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**PROBLEM:** There were no historical precedents and, therefore, no established protocols for teaching individuals to use voice-controlled assistive devices such as the robotic aid. The Interactive Evaluation Model calls for user input during the prototype development stages of the robotic aid. Training is required in order to maximize the breadth and depth of user input to the robotic aid designers and developers.

**SIGNIFICANCE:** Training is a critical component to acceptance of any advanced technological device. Training has particular importance when computerized, interactive devices, such as the robotic aid, are involved. As Vaughn & Fryberger (1982) state, *"essential ingredients to user acceptance of the system [online, interactive computer system] have been user involvement, user training... It is also necessary for adequate training to be implemented and persisted with, if maximum usage is to result from provision of functional appliances."*

**BACKGROUND:** Development of training procedures began during the spring of 1982. The primary method for teaching individuals how to use the robotic aid was verbal one-to-one communication. Systematic development of training procedures commenced in September, 1982 within the framework of the Interactive Evaluation Model.

**HYPOTHESIS:** We hypothesized that the following goals could be realized through interactive training: (a) development of successful user/machine profiles, (b) better understanding of how training affects the process of learning to control the robotic aid, (c) examination of the role of training in increasing the user's perception of control of the general environment, (d) generation of data that will illuminate the barriers to user acceptance and technology dissemination, (e) development of a training manual for users and trainers, (f) evaluation of the training procedures and training biases.

**APPROACH:** Four factors, described in the Interactive Evaluation Model, interact during the training process to determine successful use of the robotic aid:

(1) Machine Characteristics
(2) Machine Performance
(3) User Characteristics
(4) User Performance

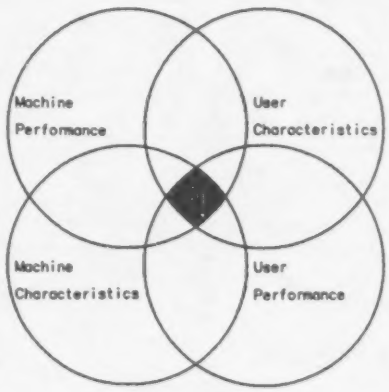


Figure 1. Training enviroment.

These factors interact in a particular training environment which includes consequent situational and training biases. Their relationship is best shown in Figure 1. Training seeks to optimize the match among the four factors in order to achieve a successful user/machine integration (see shaded area in Figure 1).

Machine characteristics under examination include: (a) operating modes: the robotic aid can be piloted in three different ways, (b) visual and verbal feedback to the user, (c) software reliability, (d) aesthetics such as size, appearance, sounds, and color, (e) the utility of a general purpose device that enables the development of user specific tasks.

Machine performance is determined in the following ways: (a) tallying procedures have been developed to monitor the number and type of incorrect recognitions by the voice system, and (b) records are being maintained on safety and reliability of the robotic aid system (number of mechanical errors and failures).

The following user characteristics affect the training process: (a) limitations such as voice quality and physical stamina, (b) cognitive characteristics such as visual-spatial ability, attention span, cognitive workload, (c) motivation, (d) learning and achieving styles, (e) prior vocational experience and education, and (f) perceived locus of control. These characteristics are assessed with questionnaires and recognized psychometric instruments, such as Rotter's I-E Scale.

Human performance is assessed by the following: (a) ability to perform a designated task, (b) time required to complete a task, (c) the number of voice commands used for task completion, (d) tallying of human errors in using vocabulary out of context, and (e) demonstration of creative use of the robot. This last parameter might include the use of a unique sequence of commands not previously taught. User self-confidence and sense of control will be determined with questionnaires before, during, and after training.

The following parameters are examined in evaluation of training procedures: (a) trainer characteristics and biases, (b) situational considerations such as time of day, (c) type of task used in training, and (d) environmental factors such as noise level and temperature.

Training is accomplished in five sessions which are one to two hours in length. During each session, the user reviews existing expertise, acquires new information, practices the lessons in both structured and unstructured manners, and finishes the session with a task that helps the user assimilate the entire lesson. Our approach employs an adult–learning theoretical framework. This methodology also includes concepts such as: self-directness, learning readiness, immediate applicability, and problem-centered learning tasks.

**STATUS:** Over 100 users have been trained to use the voice-controlled robotic aid. They range in age from 5 to 72 years and include 25 high level spinal cord injury patients, primarily inpatients and outpatients from PAVAMC Spinal Cord Injury Service. A 200 page manual has been developed and utilized by people with widely varied educational levels. These levels range from less than a high school degree to both technical and non-technical Ph.Ds, as well as M.D.s.

All users, particularly quadriplegic users, expressed enthusiasm upon learning to use the robotic aid. The advantages of a general purpose device were corroborated by the many users who could imagine the robotic aid in their home settings. The most often requested tasks include: (a) obtaining a drink of water, (b) cooking and serving a meal, (c) self-feeding, (d) handling clothes and other personal belongings, (e) picking up dropped items, (f) fetching objects, (g) selecting and replacing personal implements, and (h) positioning/adjusting small items. All users learned to pick up a cup within one hour of their first introduction to the robotic aid system. Mobility for the robotic aid is frequently requested as an essential feature if this device is to be practical. The users also expressed a desire for several robotic aids to assist them in their daily living.

One therapeutic application was unexpected. Users develop and/or refine visual monitoring skills while learning to use the robotic aid. One user generalized this improved skill by applying it to the challenge of visually monitoring his own sensory deprived limb.

Development of standardized training procedures for instructing trainers is currently underway. A "peer training" program is also being developed to match user and trainer according to age or personal rehabilitation experience. Both self-paced and trainer-paced training styles are being refined in order to conduct locus of control studies. These studies are designed to assess our ability to optimize successful use of the robotic aid by matching a particular training style with a particular set of user characteristics.

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Project support: Merit Review
RR&D base resources and funding

# EVALUATING THE DISSEMINATION OF REHABILITATION TECHNOLOGY: THE HEALTH SERVICES RESEARCH PERSPECTIVE


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**PROBLEM:** The Interactive Evaluation Model calls for examination of technology transfer as part of the prototype evaluation process. Technology transfer has several components which must be systematically examined if end-users are to actually realize the benefits of rehabilitation research and development. A previously under-researched component is how new rehabilitation technologies move through our health care delivery system in route to the end-users. Certain communication and structural factors significantly affect the diffusion of innovative technologies, yet this process is not well understood by developers or manufacturers

**SIGNIFICANCE:** Research of rehabilitation technology from a health services research perspective is important because most users acquire rehabilitation technology through our health care delivery system. The health care reimbursement mechanisms generally determine which services and products are provided and, therefore, exert significant influence on what rehabilitation innovations actually reach the end-user. This process has not been rigorously examined nor discussed in the literature.

This issue is becoming increasingly important with the greater use of lifesaving technologies which enable people of all ages to survive with disabilities. Rehabilitation technologies have the potential for reducing longterm health care costs by decreasing institutionalization, increasing vocational potential. Their diffusion and utilization, however, remain poorly understood.

**BACKGROUND:** Most rehabilitation technology is reimbursed under the category of durable medical equipment (DME). DME is reimbursed if it is "medically necessary". This medical necessity is determined by physician prescription and validated by physician "consultants" hired by the reimbursers. Most (if not all) reimbursers have some form of an *approved* list which documents what will be reimbursed and the amount paid per item. While these systems usually have a category for *unlisted* items — allowing the opportunity for innovations to be reimbursed — they lack the machinery to establish baseline information about the innovative rehabilitation technologies. Furthermore, no data exist to analyze the types of innovations which are being reimbursed because of the current record keeping systems. This has occurred because information about all unlisted equipment is usually stored in one combined category, and therefore, no records exist to indicate which innovations, if any, are being funded. In addition, if it is kept, it is proprietary and generally unavailable for analysis. (This is also true of Medicare reimbursement because proprietary fiscal intermediaries administer the Medicare program.)

One major effect is the creation of barriers of information flow created by this administrative structure. The existing structure also results in a lack of uniformity of decision because reimbursement is dependent on the persuasiveness of the prescription and the biases of the reimburser's medical consultant.



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**HYPOTHESIS:** Our hypothesis is that user acquistion of innovative rehabilitation technology can be improved if the system which delivers that technology is better understood. It is expected that this increased knowledge will identify factors in the health care delivery system which could be modified in order to facilitate user acquistion of rehabilitation technology, especially innovative technology.

**APPROACH:** Our approach is both theoretical and applied, including quantitative and qualitative measures. Theories from health services delivery, economics, diffusion, sociology, political science, and medicine will be examined for their applicability to the rehabilitation situation. Modifications of those theories to improve their utility in this application will be suggested.

Quantitative analysis of data will require both parametric and non-parametric statistical protocols as little precedent exists. We will provide recommendations for improving data collection and data quality so that future analyses will be more definitive. We plan formal and informal surveying of providers, administrators, and consumers. Our initial intent is to establish baseline descriptive information as to what technologies are being provided, and by whom.

**STATUS:**

The primary research effort to address this need, thus far, has been a Stanford University Medical School masters thesis which followed the approach outlined in this report (Awad, 1983). Working under the Interactive Evaluation framework, the thesis applied a theoretical diffusion model to the rehabilitation situation and focused its qualitative and quantitative analysis on MediCal (California's Medicaid program) reimbursement of wheelchairs. The policy recommendations derived from these analyses can be summarized as follows:

(1) Reclassify "Unlisted" DME items into functional categories so that diffusion and utilization of rehabilitation innovations can be tracked;
(2) Expand the *need* requirement from "medically necessary" to "necessary for daily living" or "necessary for as much independence as possible";
(3) Explicitly include engineers in the DME reimbursement decision-making process along with physicians;
(4) Improve physician knowledge of rehabilitation and the applications of rehabilitation technologies;
(5) Include prescriptive information in the development process;
(6) Recommendations for areas of research. The following is a non-exhaustive list of research that is required to fill the gaps in the existing information available on these issues:

- Examine potential role of reimbursement policies in design and development of rehabilitation technology.
- Longitudinal research to ascertain use and diffusion over time. This will facilitate the study of maintenance and repair as well as patient compliance aspects of DME use.
- Comparison of DME reimbursement between public and private payers. For instance, do private insurers provide higher quality, more expensive DME in the short term in order to decrease costs in the long term?
- Study the age and sex factors in the use of rehabilitation technologies and innovations.
- Study the cost-effectiveness of rehabilitation technologies and their potential for decreasing a) health care costs, b) institutionalized health care costs.
- Survey physicians to assess their familiarity with rehabilitation devices, the DME acquisition process, and justification writing. Target methods for improving physician knowledge in these areas.
- Survey hospital discharge planners and rehabilitation nurses to evaluate their knowledge of rehabilitation technologies and examine ways to better coordinate their activities to facilitate more complete and efficient patient care.

- Study whether the bureaucratic process actually serves as a deterrent to marginal, optional, and fraudulent claims, and whether any significant cost savings are yielded as a result.

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Project support: RR&D base resources and funding
Merit Review

# THE STUDY OF MANIPULATOR MOTION UNDER CONSTRAINT

LARRY J. LEIFER, Ph.D. — Principal investigator, VA and Stanford
CHARLES BUCKLEY, MSME, MSEE — Biomedical engineer, VA and Stanford

**PROBLEM:** Research in hybrid man-machine manipulation systems has identified the need for automatic trajectory generation of manipulator motions. The principle of such hybrid systems is that an operator always has the option of guiding a manipulator through a motion under manual control. However, if a task is easier to describe to the dedicated assistive computer which makes these systems possible than it is for the operator to carry it out manually, the operator may asks for a motion to be completed under computer control. Algorithms are sought which generate manipulator motion trajectories through cluttered environments such as table tops given only descriptions of initial and final states.

**SIGNIFICANCE:** A number of hybrid man-machine manipulation systems have been built and evaluated, e.g. [Brooks, Buckley]. The device described in [Buckley] is currently being evaluated in other research at RR&D. While it cannot be disputed that such devices increase the manipulative capabilities of the operator that they serve, the degree of useful computer assistance available from these systems has been minimal. This is due mainly to the high complexity required to describe manipulator motions in sufficient detail for them to be executed under computer control.

If such systems are ever to become more than laboratory curiosities, the burden of making implicit information about motions explicit enough for execution must be shifted from the human operator to the assistive computer of the system. Along with the development of an effective human interface, this is a fundamental problem in this field.

The generation of unencumbered trajectories from endpoint information has been widely accepted as a near-term goal in the pursuit of manipulator intelligence. Nearly every duty which has been proposed for manipulative aids for the handicapped implicitly requires some form of this capability in order to function safely. It achievement is therefore of paramount importance.

**BACKGROUND:** A number of algorithms have been developed and evaluated for solving this problem. These algorithms fall into two categories. In one category are algorithms which rely on heuristics to generate trajectories, such as [Peiper, Khatib]. Although these algorithms operate in real-time, their success rate is low.

On the other hand, exhaustive algorithms have been developed which work by partitioning all possible states of a manipulator into a finite number of isotopic sets, and determining adjacency relationships between them. Examples of such algorithms are described in [Lozano-Perez, Schwartz]. Searches for paths between initial and final goal states which pass through admissible and adjacent sets are then performed exhaustively. While such algorithms can be shown to terminate, they require many human lifetimes to solve for a trajectory of modest size.

**HYPOTHESIS:** It is hypothesized that the poor performance of heuristic algorithms for trajectory generation can be significantly improved through development of heuristics which are closely related to the numerical structure of the problem itself. Previous studies of heuristic algorithms have seen fit to terminate upon demonstration of the concept of heuristic-driven trajectory generation, without evaluating the particular heuristics used. This research begins where these early studies leave off.

It is further hypothesized that through use of properly developed heuristics, sufficiently reliable assistive devices may be developed to finally be accepted and used by severely disabled patients.

**APPROACH:** The primary difficulty in manipulator trajectory generation is that of characterizations of collisions. Given an adequate model of the world in which a manipulator operates, it is very easy to determine on a yes-or-no basis if a manipulator may be placed in a given position. It is not as easy to numerically characterize the relative "badness" of two manipulator positions in terms of some performance index. Such a characterization is useful in determining how to modify a manipulator position so as to eliminate possible collisions.

It is therefore sought to develop a strong, mathematically consistent numeric characterization of a manipulator moving among obstacles. Having done this, it is sought to apply previous results in numerical analysis to the computer generation of valid trajectories.

**STATUS:** The formulation of the trajectory generation problem as a non-linear programming problem has been accomplished. This includes the development of a piecewise-differentiable constraint function which characterizes collisions which is valid for the entire problem domain. As far as is known, this work is original.

Algorithms have been developed for efficiently calculating these functions for polyhedral sets. Implementation of these algorithms is near completion.

The investigation of numerical algorithms for computing trajectories which take advantage of this formulation is currently in progress.

This work is being carried out in collaboration with and using the facilities of the Fairchild Laboratory for Artificial Intelligence Research, 4001 Miranda Avenue, Palo Alto, Cal. 94303.

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Project support: Merit Review
RR&D base resources and funding

## IMAGES PROJECT


| | |
|---|---|
| MICHAEL R. ZOMLEFER, Ph.D. | Principal investigator, VA and USC |
| GREGORY GOODRICH, Ph.D. | Co-investigator, VA and U.C. Berkeley |
| LARRY L. LEIFER, Ph.D. | Co-investigator, VA and Stanford |
| ROBERT CHASE, M.D. | Co-investigator, VA and Stanford |
| MACHIEL van der LOOS, Dipl.Engr. | Co-investigator, VA and Stanford |


**PROBLEM:**

A. Externally Powered Mobility

While general specifications for a personal vehicle can be stated, there has been little effort to develop the tools needed for a systematic research, development, and evaluation program. This problem is encountered when one attempts to increase user access to existing powered wheelchairs and/or improve wheelchair performance for current users.

1. Who can use existing powered wheelchairs safely?
2. Under what operating circumstances can they be expected to perform satisfactorily?
3. What are the key features of existing wheelchairs which facilitate or limit their effectiveness?
4. What percent of the potential users elect to remain immobile because they *"don't like"* existing wheelchairs?
5. What are the key features needed to make powered wheelchairs more accessible?

B. Low Vision

While general specifications for a personal vehicle can be stated, there is no equivalent knowledge base for research and development related to low vision aids. This is particularly true for mobility and orientation. And, while the situation is better with respect to reading aids, there is profound need for new tools to study low vision phenomena and a systematic development program to utilize the knowledge gained. The performance of the rehabilitation community in bringing new technology to bear on this class of problems is particularly notable as the field of robotics moves towards the realization of general purpose machine vision systems, while we waste the chance to help low vision individuals effectively use the vision they already have.

1. What does the individual with macular degeneration, retinitus pigmentosa, or a cataract really see?
2. How could the visual world best be "enhanced" for presentation to a specific individual's retina?
3. What training procedures will maximize performance while taking individual preference into account?
4. What are the critical performacne specifications for the next generation of diagnostic, training, mobility, and reading aids?

**SIGNIFICANCE:** It is uniquely possible in simulation studies to SIMULTANEOUSLY MEASURE PERFORMANCE and PREFERENCE. This unique capability facilitates the maintenance of a balanced R&D program. Typically, technical members of the development team are biased in their consideration of the technical aspects of system performance. Medical members of the team are biased to evaluate the physiological performance of the patient. Only the patient/user is biased in favor of his/her own preference. And, it is preference which determines what devices will and will not be used after the patient goes home.

**HYPOTHESIS:** It is hypothesized that simulation science and technology should play a central role in rehabilitation. There are three key levels of implementation:

1. General purpose high performance simulation is needed to define the limits of human and machine performance and to define the necessary and sufficient conditions for solving specific problems. Such systems are powerful, complex, and require highly skilled operators.
2. Task specific simulation is needed for clinical diagnostics, treatment, and professional training. Moderate operator skill is required. The specifications for such systems may be derived from basic studies.
3. Personal (single user) simulators are needed for extended therapy and performance maintenance. They would be used at home, user owned and user operated. Their specification would be derived from basic studies and confirmed in the clinical setting.

**APPROACH:** Using the simulator gift (see below) from Singer Link Company, the following three-part effort will be undertaken:

1. A graphic data base will be constructed and developed that can be used for both low vision and wheelchair studies. A single setting, that of the Stanford Shopping Center, has been chosen for both studies.
2. A pilot study will be performed to assess the feasibility of using Digital Image Generator (DIG) technology in the study of wheelchair mobility. The dynamic equations of motion for an existing wheelchair have already been derived in the course of our ongoing work on wheelchair controls. With minor parametric changes, our initial wheelchair pilot study can be based on existing software. The driving environment will be that of the Stanford Shopping Center data base indicated above.
3. A pilot study will be performed to assess the feasibility of using DIG technology to study the impact of low vision perception on mobility. It is believed that this study can (for now) best be done in the context of low vision wheelchair use.

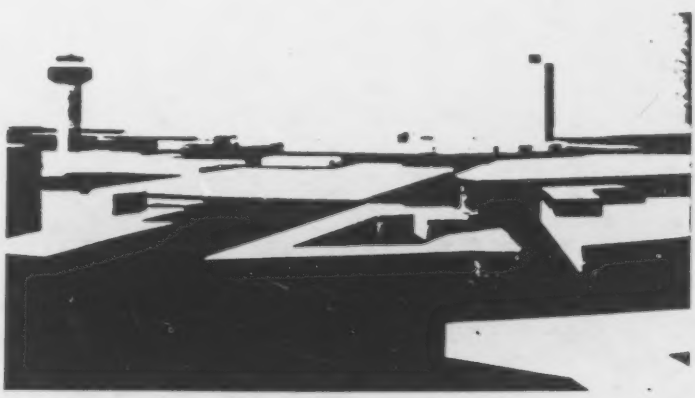

Figure 1. Photo of Las Vegas: High resolution B&W rendition of original color scene generated by DIGS.

## Current Merit Review Activity

Boylls, C., Zajac, F., and Zomlefer, M.
Olivocerebellar Mechanism of Motor Coordination
Medical Merit Review
$161,000 for 3 years requested
$146,000 for 3 years funded (FY82)

Csongradi, J. Perkash, I., and Koogle, T.
External and Internal Stabilization of the Disrupted Cervical Spine
RR&D Merit Review
$162,000 for 3 years requested
$121,000 for 3 years funded (FY81)

Engelhardt, K., Perkash, I., and Leifer, L.
Rehabilitation Research Evaluation and Learning Laboratory
RR&D Merit Review
$374,250 for 3 years requested (FY84, approved, pending funding)

Goodrich, G., and Jaffe, D.
Development of a Graphic Braille Display
RR&D Merit Review
$69,600 for 2 years requested (FY84, approved, pending funding)

Hentz, V., Leifer, L., and Abraham, G.
Toward Better Methods of Nerve Repair and Evaluation
RR&D Merit Review
$100,000 for 2 years requested and funded (FY81)
$202,045 for 3 years requested and funded (FY83 renewal)

Jaffe, D.
Ultrasonic Head Control Unit
Paralyzed Veterans of America
$44,000 for 1 year requested
$17,000 for 1 year funded (FY82)

La, W. (Smith, R.), Perkash, I., Leifer, L., Koogle, T., and Jaffe, D.
Development and Evaluation of Wheelchair Feedback Controllers
RR&D Merit Review
$171,400 for 2 years requested
$167,900 for 2 years funded (FY82)

Leifer, L., Engelhardt, K., and Steele, R.
The Dissemination of Rehabilitation Technologies
RR&D Merit Review
$224,500 for 3 years requested (FY84, approved, pending funding)

Leifer, L. and Perkash, I.
Development and Evaluation of a Robotic Aid for the Severely Disables
RR&D Merit Review
$325,000 for 3 years requested and funded (FY78)
$721,000 for 3 years requested and funded (FY80 renewal)

Perkash, I. and LeBlanc, M.
Seating System for Body Support and Prevention of Tissue Trauma
RR&D Merit Review
$267,000 for 3 years requested and funded (FY81)

Sabelman, E.
Diagnosis and Treatment Compatible Spinal Injury Patient Stabilization and Transport Device
RR&D Merit Review
$35,274 for 1 year requested (FY84, pending)

Wood, S. (Steele, R.)
Development of a Camera for Application in Sensory Aids for the Blind
RR&D Merit Review
$187,000 for 2 years requested and funded (began FY81, continued thru FY83)

Zajac, F., Levine, W., and Zomlefer, M.
Intermuscular Coordination of Mammalian Movement
NIH
$191,000 for 2 years requested
$193,500 for 2 years funded (FY82)
$428,735 for 3 years requested (FY84 renewal, pending)

Zomlefer, M., and Gaines, R.
The Spinal Locomotion Pattern Generator in Humans
Medical Merit Review
$25,000 for 1 year requested
$12,100 for 1 year funded (FY82)

## Student Involvement in RR&D Center Projects

Students are an integral part of the RR&D Center concept. Much of the productively in our first years can be directly attributed to student projects advised by faculty participating in the formation of the Center. These projects have proven to be exceptionally effective in the exploration of new assistive device concepts. Under the largess of *student pilot projects* we have performed the preliminary studies from which merit review proposals were written and Center staffed projects funded.

Beyond project specifics, we are fundamentally concerned with the education and training of engineers and physicians. It is our intent to give them the best possible technical learning experience in conjunction with exposure to the excitement and challenge of interdisciplinary research and development in rehabilitation. We expect to attract the best of the medical students and the best of engineering graduate students. While we involve many master's degree candidates in our projects, our primary concern is with the education of Rehabilitation Scientists, Ph.D.s and M.D.s specializing in rehabilitation. These people are needed to establish Academic Rehabilitation.

Student involvement in RR&D Center projects is tablulated here using the following format. The association between individual students and Stanford contracts may be obtained from the university's accounting records. Note that students do not receive any salary or stipend for their work on *student pilot projects*. Research Assistants (RAs) do receive a stipend.

| | |
|---|---|
| TITLE | project title |
| STUDENTS | names and degree candidacy of participating students |
| ADVISOR | faculty advisor to the project |
| COURSE | specific course in which credit was earned for the work performed |
| LIAISON | names of VA employees providing technical or clinical guidance |

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FISCAL YEAR 1978

| | |
|---|---|
| TITLE | PERSONAL INFORMATION SYSTEM FOR THE VISUALLY IMPAIRED |
| STUDENTS | Greg Flowler, Engr.D., (RA) |
| ADVISOR | Professor John Linvill, Ph.D. |
| | Professor Martin Morf, Ph.D. |
| COURSE | EE301, Engineering Special Problems (Thesis) |
| LIAISON | Greg Goodrich, Ph.D., VA WBRC |

| | |
|---|---|
| TITLE | ENVIRONMENTAL CONTROL FOR QUADRIPLEGICS |
| STUDENTS | David Kelley, M.S., (RA) |
| | James Sachs, M.S., (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME 291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | QUANTITATIVE ELECTROMYOGRAPHY OF THE URETHRAL SPHINCTER |
| STUDENTS | Edith Wilson, M.S., (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | EXERCISER FOR UPPER LIMB SPASTICITY |
| STUDENTS | Tom Woo, M.S. candidate |
| | Ken Allen, M.S. candidate |
| | Peter Axelson, B.S. candidate |
| ADVISOR | Professor Philp Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D. |

| | |
|---|---|
| TITLE | A MODULAR SEATING AND MOBILITY SYSTEM |
| STUDENTS | Jonathan Flam, M.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Wally Mottlock, O.P., CH@S REC |

| | |
|---|---|
| TITLE | A KITCHEN STORAGE SYSTEM FOR PARAPLEGICS |
| STUDENTS | David Lima, M.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Christine Wright, O.T., VA SCIS |

| | |
|---|---|
| TITLE | TWO HANDLED SPOON DEVELOPMENT AND EVALUATION |
| STUDENTS | Gregory Shaw, M.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Christine Wright, O.T., VA SCIS |
| | Wally Mottlock, O.P., CH@S REC |

| | |
|---|---|
| TITLE | BODY BAROGRAPH FOR MEASUREMENT OF SURFACE PRESSURE DISTRIBUTIONS |
| STUDENTS | Mary Springhorn, M.S. |
| | John Kirby, M.S. |
| | Tom Kinney M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |

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|---|---|
| TITLE | QUADRIPLEGIC REACHER |
| STUDENTS | JoAnne Bessler, BSPD |
| | Dave Uken, B.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Christine Wright, P.T., VA SCIS |

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|---|---|
| TITLE | MUSIC SYNTHESIZER INTERFACE FOR THE PHYSICALLY DISABLED |
| STUDENTS | Peter Aschenbrenner, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Christine Wright, P.T., VA SCIS |

| | |
|---|---|
| TITLE | ELECTRONIC GAMES TABLE FOR QUADRIPLEGICS |
| STUDENTS | James Holmes, B.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |

| | |
|---|---|
| TITLE | A MULITIPLE DOSE PILL PACKAGING SYSTEM |
| STUDENTS | Carl Stern, BSPD |
| | Tamiko Thiel, BSPD |
| | William Shriver, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Ronald Sharp, Pharmacist, VAMC |

| | |
|---|---|
| TITLE | A COMMUNICATION DEVICE FOR PHYSICALLY IMPAIRED ADULTS |
| STUDENTS | Peggy Christiansen, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Sandi Enders, O.T., CH@S REC |

| | |
|---|---|
| TITLE | SELF FEEDER FOR CEREBRAL PALSY PATIENTS |
| STUDENTS | David Cannon, B.S. |
| | Weston Press, B.S. |
| | Robert Werle, B.S. |
| | David Worms, B.S. |
| ADVISOR | Professor Ernest Chilton, Ph.D. |
| COURSE | ME113, Senior Machine Design |
| LIAISON | Wally Mottlock, O.P., CH@S REC |

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FISCAL YEAR 1979

| | |
|---|---|
| TITLE | REHABILITATION OF NEURAL TRANSMISSION |
| STUDENTS | Gordon Abraham, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| | Professor Larry Leifer, Ph.D. |
| COURSE | EE29, Individual Laboratory Projects |
| LIAISON | Rodney Hentz, M.D., VA Reconstructive Surgery |

| | |
|---|---|
| TITLE | REHABILITATION OF URETHRAL MUSCLE FUNCTION |
| STUDENTS | Stephan Jacklin, M.S., (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | STRUCTURAL PROPERTIES OF BONE AND CONNECTIVE TISSUE |
| STUDENT | Elizabeth Meyer, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Robert Piziali, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Donald Nagel, M.D., Orthpaedic Surgery, Stanford |

| | |
|---|---|
| TITLE | HEAD CONTROL UNIT FOR PILOTING A ROBOTIC ARM |
| STUDENTS | William Shriver, M.S. |
| | Paul Justle, M.S. |
| | Steve Tipton, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |

| | |
|---|---|
| TITLE | BODY BAROGRAPH FOR MEASUREMENT OF SURFACE PRESSURE DISTRIBUTIONS |
| STUDENTS | Mary Springhorn, M.S. |
| | John Kirby, M.S. |
| | Tom Kinney M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |

| | |
|---|---|
| TITLE | NO GRASP REACHER |
| STUDENTS | William Scott, MFA |
| | Hal Kent, B.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Christine Wright, O.T., VA SCIS |

| | |
|---|---|
| TITLE | UPPER-LIMB ERGOMETER COMPATIBLE WITH WHEELCHAIR AND BED USAGE |
| STUDENTS | Mike Barker, M.S.<br>Jim Dornbusch, M.S.<br>Humberto Rincon, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D.<br>Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D., VA SCIS<br>Richard Ferdinand, P.T. VA SCIS |

| | |
|---|---|
| TITLE | A WALK-IN BATHING SYSTEM FOR ELDERLY INDIVIDUALS |
| STUDENTS | BoFat Chan, M.F.A. |
| ADVISOR | Professor Robert Mckim<br>Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Christine Wright, O.T., VA SCIS |

| | |
|---|---|
| TITLE | WHEELCHAIR DESIGN STUDY |
| STUDENTS | David Willis, MFA |
| ADVISOR | Professor Robert McKim<br>Professor Larry Leifer, Ph D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Richard Ferdinand, P.T., VA SCIS<br>Wally Mottlock, O.P., CH@S REC |

| | |
|---|---|
| TITLE | NO GRASP DOOR OPENER FOR QUADRIPLEGICS AND PERSONS WITH ARTHRITIS |
| STUDENTS | Lee Winick, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Christine Wright, O.T., VA SCIS |

| | |
|---|---|
| TITLE | THE ARROYA DOWNHILL SKI-SLEDDING SYSTEM FOR PARAPLEGICS |
| STUDENTS | Peter Axelson, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Inder Perkash, M.D., VA SCIS<br>Robert Montero, M.D., VA PM&R |

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FISCAL YEAR 1980

| | |
|---|---|
| TITLE | DEVELOPMENT AND EVALUATION OF A ROBOTIC AID |
| STUDENTS | Charles Wampler, M.S., Ph.D. candidate (RA) |
| | John Jameson, M.S., Ph.D. candidate (RA) |
| | Charles Buckley, M.S., Ph.D. candidate (RA) |
| | Rickson Sun, M.S., Engr.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME301, Thesis Research |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | REHABILITATION OF NEURAL TRANSMISSION (continuing) |
| STUDENTS | Gordon Abraham, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| | Professor Larry Leifer, Ph.D. |
| COURSE | EE291, Individual Laboratory Projects |
| LIAISON | Rodney Hentz, M.D., VA Reconstructive Surgery |

| | |
|---|---|
| TITLE | REHABILITATION OF URETHRAL MUSCLE FUNCTION (continuing) |
| STUDENTS | Stephan Jacklin, M.S., (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | STRUCTURAL PROPERTIES OF BONE AND CONNECTIVE TISSUE |
| STUDENT | Elizabeth Meyer, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Robert Piziali, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Donald Nagel, M.D., Orthpaedic Surgery, Stanford |

| | |
|---|---|
| TITLE | ON THE FEASIBILITY OF ROBOTIC AIDS FOR THE SEVERELY DISABLED |
| STUDENTS | Charles Buckley, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | HUMAN KNEE MECHANICS ASSOCIATED WITH GAIT AND SUPPORT PROBLEMS |
| STUDENTS | David Fyhrie, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Robert Piziali, Ph.D. |
| COURSE | ME219, Individual Laboratory Projects |
| LIAISON | Donald Shurman, M.D., Orthopaedic Surgery, Stanford |

| | |
|---|---|
| TITLE | SENSATE ROBOTIC HAND |
| STUDENTS | Rickson Sun, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Robert McKim |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Rodney Hentz, M.D., VA Hand Surgery Center |

| | |
|---|---|
| TITLE | BICYCLE FOR PARAPLEGICS |
| STUDENTS | Douglas Schwandt, M.S. |
| | Candy Mintz, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |
| | Peter Axelson, B.S., RR&D Center |

| | |
|---|---|
| TITLE | SMART WHEELCHAIR |
| STUDENTS | Karen Altman, M.S. |
| | Richard Epstein, M.S. |
| | Leslie Gerding, M.S. |
| | Wayne Leger, M.S. |
| | David Parker, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| | ME218ab, Smart Product Design |
| LIAISON | David Jaffe, M.S., RR&D Center |

| | |
|---|---|
| TITLE | ORIENTATION ALGORITHM FOR SENSATE HAND |
| STUDENTS | Jim Woodward, M.S. |
| | Walter Hardt, M.S. |
| | Angio Jaccard, M.S. |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| | Professor Larry Leifer, Ph.D. |
| COURSE | EE280ab, Computer Applications Laborator |
| LIAISON | David Jaffe, M.S., RR&D Center |
| | Rickson Sun, M.S. |

| | |
|---|---|
| TITLE | UPPER LIMB ERGOMETER |
| STUDENTS | James Sacherman, BSPD |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | Christine Wright, O.T., VA SCIS |
| | Richard Ferdinand, P.T., VA SCIS |

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FISCAL YEAR 1981

| | |
|---|---|
| TITLE | DEVELOPMENT AND EVALUATION OF A ROBOTIC AID (continuing) |
| STUDENTS | Charles Wampler, M.S., Ph.D. candidate (RA) |
| | John Jameson, M.S., Ph.D. candidate (RA) |
| | Charles Buckley, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME301, Thesis Research |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | HUMAN FACTORS AT THE MAN-COMPUTER INTERFACE |
| STUDENTS | Richard Vistnes, MSCS, Ph.D. candidate (RA) |
| ADVISOR | Professor Thomas Binford, Ph.D. |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | MICROCOMPUTER CONTROLLER FOR THE SMART WHEELCHAIR |
| STUDENTS | Thomas Vink, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | David Jaffe, M.S.D, VA RR&D |

| | |
|---|---|
| TITLE | STRUCTURAL PROPERTIES OF BONE AND CONNECTIVE TISSUE |
| STUDENTS | Ataullah Arjomand, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Robert Piziali, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | David Shurman, M.D., Orthopaedic Surgery, Stanford |

| | |
|---|---|
| TITLE | UNDERSTANDING OF HUMAN PITCH PERCEPTION |
| STUDENTS | Mitchel Weintraub, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Joseph Goodman, Ph.D. |
| COURSE | EE301, Thesis Research |
| LIAISON | Professor Earl Schubert, M.D., Surgery, Stanford |

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|---|---|
| TITLE | A SIX-DEGREE-OF-FREEDOM MANIPULANDUM FOR REMOTE MANIPULATION |
| STUDENTS | Machiel Van der Loos, Dipl.Engr., Eng.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME301, Thesis Research |
| LIAISON | Inder Perkash, M.D., VA SCIS |

| | |
|---|---|
| TITLE | HUMAN KNEE MECHANICS ASSOCIATED WITH GAIT PROBLEMS (continuing) |
| STUDENTS | David Fyhrie, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Robert Piziali, Ph.D. |
| COURSE | ME219, Individual Laboratory Projects |
| LIAISON | Donald Shurman, M.D., Orthopaedic Surgery, Stanford |



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|---|---|
| TITLE | MODELING NEUROMUSCULAR STIMULATION OF THE UPPER EXTREMITY |
| STUDENTS | Felix Sheu, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Felix Zajac, Ph.D. |
| COURSE | ME291, Individual Laboratory Projects |
| LIAISON | Ronald Angel, M.D., VA Neurology |

| | |
|---|---|
| TITLE | OMNIDIRECTIONAL ROBOT MOBILITY BASE |
| STUDENTS | Mike Hightower, M.S. |
| | John Reinersten, M.S. |
| | Richard Steidle, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| | ME218ab, Smart Product Design |
| LIAISON | William La, Ph.D., VA RR&D |
| | Timothy Koogle, Engr.D., VA RR&D |
| | Brian Carlisle, M.S., Unimation Inc. |
| | Donald Allen, M.S., Unimation Inc. |

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|---|---|
| TITLE | STIMULUS ARTIFACT SUPPRESSION IN NERVE ACTION POTENTIAL RECORDING |
| STUDENTS | Bruno Berlizot, M.S. |
| | Kelley Leutkmeyer, M.S. |
| | Dwight Nishimura, M.S. |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| COURSE | EE280, Computer Applications Laboratory |
| LIAISON | Kenneth Cummins, Ph.D., VA RR&D |
| | Leslie Dorfman, M.D., VA RR&D, Stanford Neurology |
| | Kevin McGill, Ph.D. candidate |

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|---|---|
| TITLE | TOTAL FITNESS SYSTEM |
| STUDENTS | James Sacherman, M.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Inder Perkash, M.D., VA SCIS |
| | John Riccaro, P.T., VA SCIS |

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|---|---|
| TITLE | A PRODUCT TO PROMOTE AEROBIC FITNESS |
| STUDENTS | David Uken, M.S. |
| ADVISOR | Professor Robert McKim |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | David Pliskin, M.S., VA RR&D |

| | |
|---|---|
| TITLE | A DIGITAL PAGER FOR THE HEARING IMPAIRED |
| STUDENTS | Tom Rhodes, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME218ab, Smart Product Design |
| LIAISON | Richard Goode, M.D., Ear Nose and Throat Surgery |

| | |
|---|---|
| TITLE | TALKING THERMOMETER |
| STUDENTS | Hans Christian Engelhardt, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME218ab, Smart Product Design |
| LIAISON | Gregory Goodrich, Ph.D., VA WBRC |
| | Dianne Morrissette, VA WBRC |

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|---|---|
| TITLE | EASY RISING CHAIR |
| STUDENTS | Richard Morrison, M.S. |
| ADVISOR | Professor Robert McKim |
| COURSE | ME211abc, Product Design Master's Project |
| LIAISON | Robert Montero, M.D., VA PM&R |

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FISCAL YEAR 1982

| | |
|---|---|
| TITLE | DEVELOPMENT AND EVALUATION OF A ROBOTIC AID (continuing) |
| STUDENTS | Charles Wampler, M.S., Ph.D. candidate (RA) |
| | John Jameson, M.S., Ph.D. candidate (RA) |
| | Charles Buckley, M.S., Ph.D. candidate (RA) |
| | Walter Conti, B.S., M.S. candidate (RA) |
| | Michael Van der Loos, Dipl.Engr., Ph.D. candidate (RA) |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME301, Thesis Research |
| LIAISON | Inder Perkash, M.D., VA SCIS |

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|---|---|
| TITLE | DETECTION OF IMAGES OF PRINT IN NATURAL SCENES |
| STUDENTS | Dean Hennies, B.S. |
| | Eric Schoen, M.S. |
| | Joe Atterbury, B.S. |
| | Syed Hassan, M.S. |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| COURSE | EE280, Computer Applications Laboratory |
| LIAISON | Sally Wood, Ph.D., VA RR&D |
| | Stuart McDonald, BSM, VA RR&D |

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|---|---|
| TITLE | BIOPHYSICAL FACTORS AFFECTING NERVE CONDUCTION VELOCITY |
| STUDENTS | A.B. Danda, MSBio/B.S. |
| ADVISOR | Professor Donald Perkel, Ph.D. |
| COURSE | Neurology 199, Directed Study |
| LIAISON | Kenneth Cummins, Ph.D., VA RR&D |

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|---|---|
| TITLE | ORATOR - A SPEECH SYNTHESIS AID FOR THE NON-VOCAL |
| STUDENTS | Steven Lee, M.S. |
| | Michael Nelson, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME218abc, Smart Product Design |
| LIAISON | Richard Steele, Ph.D., VA RR&D |
| | Sally Wood, Ph.D., VA RR&D |
| | Peggy Barker, MSRE, CH@S REC |

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|---|---|
| TITLE | HEAD HIGH OBSTACLE DETECTOR |
| STUDENTS | Steve Bayer, M.S. |
| | Tom Saxe, M.S. |
| ADVISOR | Professor Larry Leifer, Ph.D. |
| COURSE | ME218abc, Smart Product Design |
| LIAISON | David Jaffe, M.S., VA RR&D |
| | Diane Morrissette, VA WBRC |
| | Sue Melrose, VA WBRC |

| | |
|---|---|
| TITLE | AUTOMATED CLINICAL EXERCISE MANAGEMENT SYSTEM |
| STUDENTS | Peter Axelson, M.S. |
| | Alan Masters, M.S. |
| ADVISOR | Professor Felix Zajac, Ph.D. |
| | Professor Larry Leifer, Ph.D. |
| COURSE | ME218abc, Smart Product Design |
| LIAISON | Ron Gaines, M.D., VA SCIS |
| | David Dungan, VA RR&D |
| | David Jaffe, M.S., VA RR&D |
| | Fred Lakin, M.A., VA RR&D |

| | |
|---|---|
| TITLE | A ROBOT HAND WITH VISION CAPABILITY |
| STUDENTS | Roger Ackerman, M.S. |
| | Kenji Mori, M.S. |
| ADVISOR | Urs Elsasser, Ph.D, Research Associate |
| | Professor Philip Barkan, Ph.D. |
| COURSE | ME210abc, Graduate Machine Design |
| LIAISON | Larry Leifer, Ph.D., VA RR&D |

| | |
|---|---|
| TITLE | LEG CIRCUMFERENCE MEASUREMENT SUPPORT |
| STUDENTS | LuAnn Piccard, B.S. |
| ADVISOR | Professor David Kelley |
| COURSE | ME116c, Advanced Product Design |
| LIAISON | David Dungan, VA RR&D |
| | Barbara Jones, P.T., VA SCIS |

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FISCAL YEAR 1983

| | |
|---|---|
| TITLE | DETECTION OF IMAGES OF PRINT IN NATURAL SCENES |
| STUDENTS | Dean Hennies, M.S. |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| COURSE | EE280, Computer Applications Laboratory |
| LIAISON | Sally Wood, Ph.D., VA RR&D |

| | |
|---|---|
| TITLE | VIDEO INSTRUCTION SYSTEM FOR THE DISABLED |
| STUDENTS | Joseph P.H. Chan, M.S. |
| | John C. Tang, M.S. |
| | Michael Ott Trainor, B.S. |
| ADVISOR | Gayle Curtis, M.S. |
| COURSE | ME 218abc, Smart Product Design |
| LIAISON | K.G. Engelhardt, B.A., VA RR&D |

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FISCAL YEAR 1984

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|---|---|
| TITLE | DEVELOPMENT OF A CAMERA FOR USE IN SENSORY AIDS FOR THE BLIND |
| STUDENTS | Jay Duluk, M.S., Ph.D. candidate (RA) |
| | Dan Gerrity, M.S., Ph.D. candidate (RA) |
| | Christopher Hughes, B.S. candidate (RA) |
| | Joanne Wilson, M.S., Ph.D. candidate (RA) |
| ADVISOR | Professor Bernard Widrow, Ph.D. |
| COURSE | EE280, Computer Applications Laboratory |
| LIAISON | Richard Steele, Ph.D., VA RR&D |
| | Dean Hennies, MS, VA RR&D |

**RR&D Center Funding History**

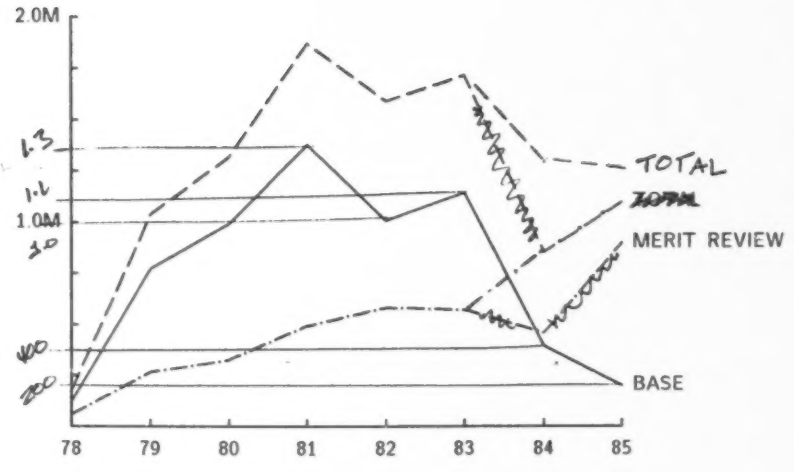


Figure 1. Funding History (FY85 is forecasted).

Base funding provides the facilities, supplies and salary foundations upon which individual projects are built.

Merit Review funding supports all major projects. These funds provide project specific support needed to accomplish research and development objectives beyond the pilot study phase. It typically takes two years from project conception to receipt of merit review funds.

## RR&D Center Facilities

NAME Rehabilitation Research and Development Center

LOCATION Building 51, V.A. Medical Center, Palo Alto, CA

The RR&D Center was occupied in June, 1980, and dedicated on September 12, 1980. The wheelchair accessible facility is adjacent to Spinal Cord Injury Service and near the Western Blind Rehabilitation Center. Space within the 80' x 80' Butler building is allocated as follows:

| Sqft | Usage |
|---|---|
| 1600 | work stations (30) |
| 740 | Neuromuscular Laboratories (includes 3 workstations) |
| 224 | RREAL Laboratory (includes 3 workstations) |
| 416 | project laboratories (3, includes 4 workstations) |
| 340 | computer room |
| 572 | prototyping facility (includes 1 work station) |
| 280 | conference area (includes 1 work station) |
| 800 | physical plant, restrooms, housekeeping |
| 1428 | corridors, ramps, etc ... |
| 6400 | total |

The building is outfitted with open modular landscape furnishings, which provides a flexible and cost effective means to alter the interior areas as needed. All utilities are routed under access flooring. A 2400 sq ft addition is scheduled to be completed and occupied about mid-summer of 1984.

NAME Neuromuscular Systems Laboratory

LOCATION Rehabilitation R&D Center, PAVAMC

PURPOSE The Neuromuscular Systems Laboratory makes possible basic scientific investigations into the biomechanics and neuromuscular control of movement in humans and animals.

RESOURCES Animal Neuromuscular Suite

Zeiss Model OPMI 6-S operating microscope with remote control
Technical Manufacturing Corp. vibration-isolated experiment table
David Kopf stereotaxic system
Burleigh Inchworm micropositioner
Bechman Model LB-2 medical gas analyzer
Nicolet Explorer digital oscilloscope
Tektronix Models 5031 and 5103 ocilloscopes
Ortek programmable stimulator (2)
Bak Electronics biphasic stimulus isolators (2)
Isopulser uniphasic stimulus isolators (6)
AMP, Inc., patch-panel interconnection system
Torbal analytical balance
Harvard respirator
VMS small-animal anesthesia machine
Blood-pressure and core-temperature monitors
Surgical instruments

Human Neuromuscular Suite

Selcom Selspot infrared movement-monitoring system (2 infrared cameras, 16 measurement diodes, 312 Hz frame sampling rate; installed and operational
LM Electronics electromyographic FM telemetry system (12 channels)
Advanced Mechanical Technology ground-reaction force plate system 2 plates)

Signal Acquisition/Analysis Equipment

EMI Model 7000 SE instrumentation tape recorder (14 channels), equipped with Kode Model 275 time-code/tape-search unit and IEEE-488 computer interface
Grass AC-coupled high-impedance recording amplifiers (6 channels)
Siemens Mingograf high-speed inkwriter (8 channels)
Bidirectional hard-wire A/D, D/A, and D/D links to RRanD Center computer facility (90 channels)

NAME IMAGES Laboratory

LOCATION Western Regional Blind Center, VA Medical Center, Palo Alto, CA

PURPOSE The IMAGES Laboratory is a research and educational facility for generating high-quality, real-time scenes for advanced vehicular and low-vision studies.

RESOURCES The IMAGES laboratory houses a digital image generation system (DIG) that was originally developed by Singer-Link Corporation for use by the aerospace community. This system includes a data base storage unit, a visual computer which functions as a system controller, image processing hardware which consists of a frame calculator, scanline computer, video generator, and a collimated visual display unit. The DIG has the capabiility to simulate atmospheric attenuation (fading), compute smooth shaded surfaces, process and display moving objects, and produce visibility effects, and it incorporates anti-aliasing circuits. The DIG is capable of displaying up to 5,000 edges/frame at a 50 Hz update rate and 8,000 edges/frame at a 30 Hz update rate. It operates at the 30 Hz update rate and displays the images on a high-resolution 1000-line, full-color CRT.

The laboratory also contains a controllable 3-degree-of-freedom motion base whose orientation can be adjusted by the host DIG system. This motion base can be used to simulate motion for vehicular research. Existing data-base includes a simulation of the Stanford Shopping Center as well as a number of low-vision and night-vision test scenes.



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NAME Rehabilitative Research Evaluation and Learning Lab (RREAL)

LOCATION Rehabilitation R&D Center, PAVAMC

PURPOSE The RREAL Lab supports the clinical evaluation and training portions of two endeavors, the Robotic Aid Project (RAP) and the Learning Lab (LLab) Project. The enclosed lab space supplies an enclosed environment for speech-related studies being done in the context of both of the projects, and provides office space for some of the researchers involved.

RESOURCES
- 224 square feet of laboratory space
- 12 linear feet of general work surface
- 1 Zilog MCZ 8-bit microcomputer for word processing
- 1 Hazeltine terminal for above wordprocessor
- 1 Zenith H19 terminal to the RR&D Center VAX

RAP:
- 1 LSI-11/2 based PUMA arm controller
- 1 PUMA-250 6-axis robot manipulator
- 1 Heavy-duty mobile work surface robot arm support
- 1 Zilog MCZ 8-bit microcomputer system
- 1 VOTRAX speech synthesizer
- 1 VOTERM voice recognition unit
- 1 VOTAN voice recognition unit
- 1 ARGUS plasma display unit
- 1 VT-100 terminal for robot system
- 1 Equipment rack for robot electronics
- 1 Sears microwave oven for robot applications
- 1 Sears refrigerator for robot applications

LLab:
- 1 APPLE II+ microcomputer system with color monitor
- 1 Shadow/VET voice recognition unit
- 1 Panasonic one-half inch VHS videotape recorder
- 1 Centronics printer
- 1 equipment rack for the above items

NAME Prototyping Facilities

LOCATION Rehabilitation R&D Center, PAVAMC

PURPOSE These facilities provide in-house capabilities to fabricate and modify prototypes.

RESOURCES Electronics Facility

oscilloscopes: Tektronix SC503, 465M, 7623A, 7603, Nicolet 2090-III
digital voltmeters: Tektronix DM502A; Fluke 8022A, 8024A
function generators: Tektronix FG502, FG504
universal bridge: Hewlett-Packard 4260A
transistor analyze: Sencore
capacitance meter: B-K 820
prom programmer: Data I/O System 19
counters: Tektronix DC503, DC504
logic probes
power supplies
breadboards
wirewrapping

Machine Facility

Metal

Bridgeport Series I milling machine with digital readout
Southbend 10 Toolroom Lathe
drill presses
spot and gas welding equipment
20" bandsaw
plus a wide variety of attachments

Wood

bandsaw
radial arm and table saws
jointer

Sheet

52" pneumatic shear
48" box break
power hand shears

General

grinders
sander
circular saw
abrasive machine (belt & disc)
solvent bath
air compressor
power drills
reamers
precision measuring tools
vises
force gages

NAME Computer Facility

LOCATION Rehabilitation R&D Center, PAVAMC

PURPOSE Several stand-alone microcomputer systems in use at the Center are dedicated to process control applications such as the Robotic Arm, the Ultrasonic Head Control Unit, Interactive Video Education System and the Omni-directional Wheelchair projects. These systems provide a means of tailoring the control functions of an aid to the capabilities of the disabled individual. The ability to master this resource is an important goal for the Center since many aids for the disabled are being designed incorporating microprocessors.

Two mini-computer systems are used to accomplish the necessary computations, analyses and control required to support programs at the Center. These systems are the primary research and development tools of the RR&D Center. One of the systems is a DEC PDP11/34 (designated LAB) which provides real-time acquisition and control of ongoing experiments and tests. The other system is a DEC VAX11/780 which provides high speed computation and manipulation of large amounts of data. The VAX and the LAB systems are linked via DecNet, a high speed interprocessor communication system.

The Lab system is configured for real-time acquisition of experiment data. The major application of this system is to support research projects underway within the Neuromuscular Systems group.

Three types of signals (data) are generated during investigations:

a. Analog signals requiring high sampling rates on multiple channels. Examples are: electromyographic, electro-oculographic and goniometric data.
b. Timing signals or interrupts which denote events and/or elapsed times, and are measured to within 1 millisecond. Examples are: trains of neuronal action-potentials obtained from brain and peripheral nerves, and switch closures indicating commencement or conclusion of electrical stimulation.
c. Digital data (eight and sixteen bit parallel) derived from laboratory equipment such as digital processing oscilloscopes and microprocessor controlled movement-analysis instruments.

During typical experiments all three of the above data types are generated. These data occur in real-time and must be processed as they occur. The Lab system is equipped with a Laboratory Peripheral Accelerator subsystem which controls multichannel analog-to-digital converters, two digital-to-analog converters and a 16 bit digital-to-digital port. A high speed (75 ips) magnetic tape drive provides mass storage for the large data streams generated during each experiment "run".

The VAX system is the principal computational resource for the Center and supports program development, mass storage, data analysis and simulations. This system also supports report generation, budget preparation and internal inventory control. The most demanding use of this system will be in modelling of nerve conduction, the multichannel analysis of the electrical activity of the brain, and finite element analysis in orthopaedic biomechanics.

The VAX system also provides a broad spectrum of capabilities pertaining to visualization of data and conversion of visual information into computer (digital) format. The specific functions of these devices and examples of their use are described below. These capabilities are provided by Tektronix graphic terminals, an incremental plotter, a high-resolution laser printer/plotter and an electrostatic printer/plotter.

The conversion of graphic data into digital format is performed by an X-Y digitizing tablet and a video digitizer. The digitizing tablet provides the capability to analyze histologic data and to digitize waveforms and images available only in picture or line-drawing formats. A specific application of this tablet is in the correlation of nerve structure with function, as in the comparison of nerve histology with conduction velocity distributions. The video digitizer is used in the conversion (to digital format) of ultrasound, X-ray or any other image requiring grey-scale resolution. This device is part of the DeAnza IP6400 Image Array Processor, which is attached to the VAX. Video picture display, analysis and manipulation are performed by the DeAnza system. The image array processor can average successive images to reduce noise, subtract or add or filter successive images to visually enhance changes in images.

RESOURCES VAX11/780

HARDWARE
32 bit processor
floating point accelerator
4 Mbytes main memory
48 terminal lines
2 high speed inter-processor communication lines (DMC11)
516 Mbyte mass storage device (RP07)
2-67 Mbyte mass storage devices (RM03)
high-resolution printer/plotter (QMS Lasergrafix 1200)
1000 LPM printer/plotter (Versatec 1200A)
Bridge CPM emulator (4 - Z80's)
DeAnza Image Array Processor (IP5532)
17x22" bed plotter (Tektronix 4663)
digitizer (HP9874A)

SOFTWARE
VMS operating system
Fortran-77, Pascal, Forth, FranzLisp, Assembler, C languages. Vax/VMS — 68000 cross-compilers for C and Pascal. VMS/CPM software emulation.
EDT, EDI, SOS, TECO, EMACS editors
DataTrieve, Interactive Laboratory System, Versaplot, TEX.
DeAnza Image Processing packages
DecNet interprocessor communication

PDP11/34

HARDWARE
16 bit processor
floating point processor
256 Kbytes main memory
1 Kword cache memory
75 ips nine track tape drive
67 Mbyte mass storage device (RM02)
2 5-Mbyte and 1 10-Mbyte mass storage devices (RL)
IEEE-488 (GPIB) interface
Laboratory Peripheral Accelerator (LPA11)
2 16-channel A/D converters
1 4-channel D/A converter (AA11-K)

2 dual programmable real time clocks (KW11-K)
16 DMA D/D controller (DR11-B)
2 16 bit D/D controller (DR11-K)
1 high speed and 1 low speed inter-processor

SOFTWARE
RSX11-M operating system
Fortran IV-Plus, Pascal, Forth, Assembler languages
EDT, EDI, EDX, TECO editors
Versaplot package, Selspot package
DecNet interprocessor communication

Z-80

HARDWARE
8 64-Kbyte systems
each with 2 8" single density floppy disk drives
Serial I/O boards
A/D, D/A, D/D

SOFTWARE
CP/M, RIO, DOS operating systems
Fortran IV, Pascal, Forth, Lisp, Basic languages
ED, PIE, Wordstar editors

NAME Graphic Communications Laboratory

LOCATION Rehabilitation R&D Center, PAVAMC

PURPOSE The Graphic Communications Laboratory (GCL) supports the advanced communications requirements of interdisciplinary research teams working on complex rehabilitation problems. Symbolic operations such as those encountered in stochastic signal estimation are rendered graphically. Massive numerical results from finite element analyses are rendered pictographically. Anatomical data from cross-sections, X-rays, and ultrasonic images are transformed into numerical records for analytic modelling. The complex dynamics of human motion are captured as video records which may subsequently be reduced by digital single frame analysis to extract key quantitative measurements. And, very importantly, visualization of ideas facilitates interpersonal communication between scientists, clinicians and clients.

RESOURCES High Resolution Digital Color Graphics System (DeAnza)
- 19" color monitor
- high resolution gray scale video camera
- image array processor

Digitizing Table (HP)
High Resolution Pen Plotter (Tektronix)
Color video camera
Portable video recorder (3/4" cassette)
Color video monitor (2)
Versaplot Software
TEX Software
Modified VT-100 graphics terminal
Mouse and interface to VT-100

## Key Stanford Facilities

NAME Smart Product Design Laboratory

LOCATION Terman Engineering Center, room 577, Stanford University

PURPOSE The Smart Product Design Laboratory (SPDL), is an educational facility for teaching electromechanical design engineers the philosophy, theory and practice of using microprocessor technology in their products.

RESOURCES The SPDL facility occupies 420 square feet on the 5th floor of the Terman Engineering Center (room 577). Following a major equipment contribution from Intel Incorporated, the laboratory is built around six (6) microcomputer development systems. Each system is configured with a maximum of memory (64K bytes), two double density 8" floppy disk drives (.5M bytes each), a Heath H19 terminal, an Epson MX-80 matrix printer and a flexible array of Input/Output interfaces. There is ample power and space in each system to support a wide variety of microcomputer development projects. A full range of programming languages are available (including: Assemblers, Fortran, PL/M, BASIC, FORTH, and PASCAL). In an important extention of SPDL capability, we support In Circuit Emulation (ICE) for the Intel 8080, 8085, 8748, and 8086/88 chip families. There is also support for the Zilog Z80 product line. After three years of growth the laboratory now has a full range of test and measurement instrumentation. The facility and staff support a balanced approach to the development and application of electronic hardware, mechanical hardware, and programming software in smart products.

As a teaching laboratory it is the curriculum which should hold our attention. The first *Smart Product Design* course was given in the Winter of 1978 as a proof of concept test. Rocky but well received, the course has since expanded to a three quarter depth sequence in the Mechanical Engineering Design Division. The course has proven to be fundamentally experimental and has changed significantly each year. The forth coming year is no exception. With the addition of a complete set of Intel development system tools, it is now possible to provide comprehensive support for a balanced hardware/software approach to product conception and development. While there is a heavy dose of technical information to be transmitted in the course, it is mainly concerned with DESIGN methodology. Accordingly, each student is required to identify and define a *smart product* of his/her own choosing. A product proposal is written during Fall quarter. Product feasibility is demonstrated during Winter quarter. And, for the highly motivated students, a functional prototype is constructed and demonstrated during Spring quarter.

NAME Interactive Robotics Laboratory

LOCATION Building 530 room 534, Stanford University

PURPOSE The Interactive Robotics Laboratory (IRL) supports a variety of research and development projects whose central theme is understanding the interaction between a human user and remote manipulation systems. In addition to man-machine integration the laboratory has projects dealing with the sensory interaction between a manipulator and its environment.

RESOURCES
- 450 square feet of laboratory space
- 6-DOF Unimation PUMA-250 electro-mechanical manipulator
- 6-DOF Unimation PUMA-560 electro-mechanical manipulator
- LSI-11/2 based arm controllers (3)
- DEC PDP 11/23 development systems (2)
  - 256K byte main memory (2)
  - RK01 disk drives (2 @ 5M-bytes each)
  - 30 Mbyte Winchester hard disk with 3" floppy backup
  - Ranyon 16K shared memory unit
  - 16 channel 12-bit ADC
  - 2 channel 14-bit DAC
  - 4 channel serial interface
  - 32-bit parallel interface
  - VT100 terminals (3)
  - Tally printer
- Zilog 1/25 Development System
  - 64K byte main memory
  - 8" diskette drives (2 @ 256K-bytes each)
  - Hazeltine 1510 terminal
- Centigram MIKE voice recognition unit (2)
- Voterm voice recognition unit
- Votrax speech synthesis unit
- Argus plasma display unit
- Tektronix test and measurement instrumentation
  - TM506 power module (2)
  - SC502 oscilloscope (2)
  - DV501 digital volt meter (2)
  - FG502 function generator (2)
  - FG504 high performance function generator
  - PG501 pulse generator
  - AM501 high gain DC amplifier (3)
  - PS503 power supply (3)
- Nicolet digital oscilloscope
- Work benches
- Mechanical hand tools

NAME Artificial Intelligence Robotics Laboratory

LOCATION Jacks Hall, room 030B, Stanford University

PURPOSE Established in 1962, the AI Robotics Laboratory has played a central role in the evolution of robotics. Hundreds of researchers have worked here to further our understanding of machine intelligence as expressed in the control of manipulators and perception of optical images.

RESOURCES 1200 square feet of laboratory space
6-DF Stanford Arm (2)
Unimation PUMA-600 Arm (2)
DEC KC-10 mainframe computer system
DEC VAX 11/780 medium scale computer system
DEC PDP 11/45 mini computer development system
Xerox Altos Computer System (6)
Flexible Assembly Line demonstration unit
MSI machine vision system
High Speed message packet network (Ethernet)
High Resolution Color Graphics System (Grinnel)

The laboratory is one part of a Computer Science Department whose considerable additional computer resources backup those of the robotics laboratory.

NAME Engineering Structures and Biomechanics Laboratories

LOCATION Located in the School of Engineering at Stanford University.

PURPOSE The Structures Laboratory is the center for research for faculty interested in the mechanical properties of materials and structures. Complementing this laboratory is the Biomechanics Laboratory for specific research on the structure and properties of the skeletal system.

RESOURCES Structures Laboratory

- MTS electro-hydraulic load frames (4 systems)
- H-P Fourier analyzer
- Redlake Labs high speed camera (up to 11,000 fps)
- Endevco signal conditioning (25 channels)
- Honeywell instrumentation tape recorder (14 channels)
- Honeywell Visicorder
- H-P 9600E mini-computer system with
  - tape drive, disc drive
  - line printer, Cal-Comp plotter (31 in)
  - Bendix digitizer, Tektronix graphics terminal
  - multiple consoles
- DEC LSI 11/V03 micro-computer system with
  - 32k core, A/D channels (16)
  - Decwriter, dual floppy discs
- MTS servo-controlled torsional test system (10,000 in/lb)
- H-P 5423A structural dynamics analyzer
- H-P 8245B plotter printer

Biomechanics Laboratory

- H-P 9845 desk top computer with A/D, D/A interface hardware
- Validune digital conditioning (14 ch)
- Force dynamometers (4) with 6 degrees of freedom
- Displacement transducer with 6 degrees of freedom
- Force dynamometer calibration stand
- Test and storage fixtures for knee experments
- Oscilloscopes
- Filters
- Signal generators and meters

NAME Electromyography and Applied Clinical Neurophysiology Laboratory

LOCATION Stanford Medical Center

PURPOSE This clinical research laboratory occupies about 500 sq ft in the neurophysiological patient care suite in the Neurology Department of the Stanford University Medical Center.

RESOURCES TECA TE-4 electromyograph and DISA 1500 electromyograph, each with
- multiple amplifiers
- mid-signal/delay capabilities
- digital signal averaging
- direct 2 ch tape recorder (TECA only)

FM tape recorder (4 ch)

Nicolet signal averagers (2) with
- stimulating and recording peripherals

Nicolet Pathfinder signal processor
- Fortran Development System
- 128k 20-bit words
- 20 Megaword cartridge disc assembly
- line printer
- terminal

DEC PDP 11/34A computer (configured for biological signal processing)
- 48k memory
- A/D (16 ch, 12 bit)
- D/A (2 ch )
- point arithmetic
- cache memory
- discs (2), 7.5 megabyte capacity
- magnetic tape (9 track at 800 BPI)
- Tektronix graphics terminal
- Versatec electrostatic printer/plotter
- UNIX and RT-11 operating systems
- Fortran IV, macro-assembler and TSL

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STATEMENT OF P. HUNTER PECKHAM, PH.D., RESEARCH BIOMEDICAL ENGINEER, VETERANS ADMINISTRATION CENTER, CLEVELAND, OH

Mr. Chairman and members of the committee, thank you for the opportunity to discuss our work in Functional Electrical Stimulation of the Upper Limbs. My name is P. Hunter Peckham and I am a Research Biomedical Engineer at the Veterans Administration Medical Center in Cleveland, Ohio, and Associate Professor of Biomedical Engineering at Case Western Reserve University. In this capacity, I lead a team of twenty-five scientists, physicians, engineers, therapists, and technicians who are developing techniques to restore functional movement and grasp to the paralyzed hand and arm. With my colleague, Dr. Marsolais, who is also appearing before you today, I am reporting on the developments in using low levels of electrical current to elicit controlled movement in the extermities, which is known as Functional Electrical Stimulation.

In many disorders of the central nervous system, the injury prevents the individual's voluntary intent from being translated into movement because of the inability of the spinal cord to transmit impulses across the damaged area. Examples of such disorders are stroke, head trauma, and spinal cord injury. Functional electrical stimulation attempts to reconstruct function by bypassing this damaged area of the central nervous system.

Electrical stimuli may be applied to the peripheral nerves, which then transmit the impulses along the nerve similarly to the way normal impulses are transmitted, and subsequently cause the muscle to contract. If the stimuli are introduced selectively to individual muscles, then the strength of each muscle may be controlled in a graded fashion. Coordinated movement of the limb may be generated by varying the degree to which each of several individual muscles is excited with respect to one another. We have been working on the development of this technique of controlling the extremities since 1968, and it is only recently that these efforts have begun to reach a level of clinical fruition. These results could not have been obtained without the contributions of knowledge of two fields. First, during this period the results from the basic sciences lead to a better understanding of the energetics of muscle contracting and its control. This enabled us to overcome the insurmountable obstacles which had plagued the earliest studies in this field. Second, the dramatic development in sophisticated microcircuitry technology has enabled engineers to design stimulator units which are sufficiently versatile to meet many of the complexities and vagrities which are required in these applications. The contributions of these two areas are fundamental in the continued development of this field.

Inability to control the hand and arms presents a devastating loss to the paralyzed individual. In the case of the individual paralyzed with midcervical level injuries, some voluntary control of the shoulder and elbow is retained, but the wrist and hand typically has neither movement nor sensation. Without this function, activities that most of us assembled here take for granted are compromised; eating, grooming, gesturing, writing, and so forth must be performed with assistance.

Our efforts have focused on the development of functional electrical stimulation to provide control of grasp and release in the hand. Our goals are modest; to enhance the function of the paralyzed extremity such that the individuals's reliance on other assistance, be it human or mechanical, is removed for substantial periods of time. Reaching such a goal will enable this individual to function independently in his home or in a working enviroment. Functional electrical stimulation systems have been implemented which enable us to demonstrate that reaching this goal is feasible. Although the goal has not, as yet, been fully realized, we have succeeded in accomplishing major strides. We have developed the means to activate the muscles, the methods by which the paralyzed individual may control the movement and strength of his grasp, and much of the hardware that is required. However, the technology employed in these systems is complex, and because major components must be surgical implanted to be most useful clinically, the biologically constraints are many. The devices must function as an integral and intimate part of the individual's body for his or her remaining lifetime. I have brought for your observation an implantable stimulator which is presently under development. The stimulator has eight channels for activation of eight separate muscles. While this device is not ready for human implantation at present, we have developed a technique which has been used in humans for ten years and is the basis for our stating that these systems are feasible. The technique is to implant small wires, or electrodes, through the skin and into the muscles and apply the electrical stimulus through these electrodes. The electrodes can be left in place for months, and in some cases years, without major difficulties. Using this technique, we have worked with over thirty sub-

jects in developing the means of enabling the quadriplegic user to obtain the use of his upper limb.

I would like to introduce to you two of my colleagues. First, Mr. James Jatich, who is an industrial engineer who sustained a spinal cord injury due to a swimming injury in August, 1977. Jim has worked with us since 1978 in developing various aspects of our research program, and for the past three months has been working with us in evaluating a system for control of his hand. The second is Mr. Geoffrey Thrope, who is a Biomedical Engineer and has been a member of our research team for five years. Jim's system uses motion of the shoulder to control grasp and release of his hand; the position of his fingers and thumb or the strength of his grasp is thus governed by his voluntary movement. Using this approach, we expect that Jim will be able to regain the ability to use his hand functionally.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions you or members of the committee wish to ask.

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STATEMENT OF E. BYRON MARSOLAIS, M.D., PH.D., CHIEF OF REHABILITATION MEDICINE, VETERANS ADMINISTRATION MEDICAL CENTER, CLEVELAND, OH

Mr. Chairman and members of the committee, my name is Byron Marsolais and I have worked at the Veterans Administration Medical Center in Cleveland, Ohio for the past 13 years and have been Chief of Rehabilitation Medicine for the last 8 years. My training has led to board certification in orthopedic surgery and a Ph.D. in engineering mechanics. Modern medicine is so complicated that maximal potential can only be achieved through total interaction of many disciplines. I have always combined the engineering and medical disciplines in approaching the care of patients with conditions ranging from simple muscular strain through amputation, stroke and even complete paraplegia.

Consider the situation of paraplegic individuals. They have no ability to move their legs—and have no sensation in them. They can only move around in a wheelchair. They cannot stand up—even for a few minutes. They cannot use most rest rooms. They cannot board an airplane without being carried. A single step can become an insurmountable barrier, restricting or preventing their attendance at an activity.

There are approximately 400,000 people with spinal cord injury in the United States today, and each year that group increases by about 10,000. My colleague, Dr. Peckham, who just addressed you, has discussed our treatment of those spinal cord injured who have lost function in both arms and legs—a condition called quadriplegia. I will discuss those with normal arms and paralyzed legs. This condition is termed paraplegia. Besides spinal cord injury, other conditions which impair the ability to walk are stroke—with 3.5 million afflicted; head injuries—2.5 million afflicted; cerebral palsy—600,000 afflicted; and multiple sclerosis—700,000 afflicted. I believe that approximately 20% of all these patients can be helped by functional electrical stimulation of muscles which cannot work effectively in the normal way.

We have begun to help selected patients who serve as subjects in our research studies at the Cleveland Veterans Administration Medical Center. The advances made have demonstrated the enormous potential of this new technology and have already begun to have an impact on the total care of the paralyzed. In the past, fractures and dislocations among paralyzed people were often left minimally treated because it was medically certain that they would not walk again. Today's best medical care has a new attitude, based on the expectation that one day the paralyzed patient may well have limited walking function.

My own research in lower extremity functional electrical stimulation started with simple stimulation of paralyzed muscles through the skin in order to treat the condition of footdrop, common in stroke patients. It soon became clear that an implanted system was necessary to give proper electrode placement. Subsequently, I surgically implanted a stimulation device provided by the Medtronic Company as part of a national study in the legs of seven patients, who were able to control the foot with a small radio frequency transmitter. These were patients whose walking was impaired by stroke or head injury. This device was too complicated to use for the control of simple footdrop; a simple brace was more reasonable. However, the experiment was important in demonstrating the feasibility of using stimulation for more complex paralysis that simple bracing could not treat.

More recently, I have been working with a group—now eight in number—of complete paraplegic patients. They have total loss of voluntary motion of the legs and they have no sensation in them. Their injuries range in level from paralysis below the breast line (a T-4 injury) to paralysis below the navel a (a T-11 injury). In our

laboratory we fabricate fine wire electrodes from stainless steel. I implant those electrodes in paralyzed muscles by first finding the right location with a very fine needle, and then inserting the electrodes by means of a hypodermic needle. The needle is removed and the flexible, coiled electrode remains in the muscle with the wire emerging through the skin. Patients have up to 70 electrodes implanted in major muscles of the hips and legs. The electrodes receive electrical stimulation from a portable computer-controlled stimulator which uses an individualized walking program for each patient. Pulses of current are delivered to the electrodes which stimulate the nerves, which in turn activate the muscle. Our method bypasses the injured spinal cord and allows the patient to send electrical stimuli directly to the muscles.

I would like to introduce Basam Khawam, Sam, who is 25 years old, and an industrial engineer. He suffered a spinal cord injury due to a gunshot wound in March 1982. He is the most advanced subject in our research study. His electrode wires are covered with a breathable plastic dressing which is impervious to bacteria. Miniature connectors, soldered to the wires, are connected to the portable computer, which allows Sam to control each function, standing, right step and left step, with stops in between.

This technique allows us to do complex experiments without major surgery. Eventually these electrodes which go through the skin, will be replaced with totally internal electrodes and an external radio frequency control. We have successfully implanted several versions of such a system in animals. With our current functional electrical stimulation system, five of our paraplegic subjects can walk, three of them with a walker, and two in parallel bars. Sam has just begun to go up stairs.

Currently the computer is set up in advance with given levels of simulation for each of the muscles; it cannot adapt to changes and it does not know if a preprogrammed step has been properly completed. The thrust of our current work is developing feedback, or closed-loop, controls that will enable the computer to intelligently adjust to changes in the environment or in the muscles themselves. Closed-loop control will improve functional electrical stimulation by allowing better balance and stability and reducing energy usage. We are concerned about the effect of the system on the body and are doing extensive computer modeling to estimate internal forces and also metabolic and bone density studies.

Functional electrical stimulation of paralyzed muscles will not free the paraplegic individual from the wheelchair, but it will make an enormous difference in the quality of life, both physical and psychological. The technology we are developing will give the paraplegic person the ability to get into an inaccessible area, through a narrow doorway, to use a commode, to stand to address a group such as this, to go up that one step which is so often the barrier preventing participation like an able-bodied human being.

### DEMONSTRATION

This research has been supported for the past 13 years by Veterans Administration funding. Last year that funding level was significantly increased allowing our research team to grow to 20 members. We have begun to make major strides beyond mere demonstration—toward a safe, reliable, adaptable system for functional walking. Continued funding will be needed to bring this project to its full potential.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions you or members of the committee wish to ask.

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### STATEMENT OF JOHN L. TRIMBLE, PH.D., ACTING DIRECTOR, REHABILITATION, RESEARCH AND DEVELOPMENT CENTER, VETERANS ADMINISTRATION HOSPITAL, HINES, IL

Mr. Chairman and members of the committee, my name is John L. Trimble, Ph. D. I am the Acting Director of the Rehabilitation Research and Develpment Center at the Hines Veterans Administration Hospital. When I came to Hines five years ago, I had almost no idea of the problems faced by people who are visually impaired. Like most normally sighted people, I had difficulty imagining being unable to read or travel independently. But, with the help of my colleagues in blind rehabilitation, I am learning.

I think the best way to appreciate one of these problems is to imagine what it would be like to read this testimony with a magnifier that makes the print 20 times larger. You would see only one word at a time and everything else would be a blur. Or, imagine that the only way you could "read" this testimony would be to listen to a tape recording of it. If you wanted to reread a passage, you would have to rewind

and replay the tape until you found it. If you were like most of the people who read like this, you would probably become frustrated, and just give up and let someone else read for you.

This is the way life is for many thousands of visually impaired veterans. They must rely on sighted readers or special aids to read almost everything. At the VA Hines Rehabilitation R&D Center, we want to make it easier for them to read. Our ultimate goal is to give visually impaired persons the ability to read whatever they want, by themselves.

Our first step toward achieving this goal was to understand the needs and abilities of the people we are trying to help. When we studied the abilities of visually impaired persons, we found two distinct groups—people without sight and people who are partically sighted. Although both groups are legally blind, their problems and needs are quite different.

We found that most visually impaired persons have some sight, and that they can read ordinary print with powerful magnifiers. However, we also found that many of them do not use these aids, because they are unhappy with them; they just do not work as well as they did when the doctor dispensed them. We concluded that the problem was not the design of the aids, but rather how they are dispensed. It is very difficult to match a partically sighted person's abilities to a particular aid. As a result, we decided to focus our efforts on improving the way these aids are prescribed. To do this, we need a better concept of what partially sighted people see. We are learning this by using computers to distort pictures so they look like they do to partially sighted people. By analyzing these pictures we hope to develop new tests for prescribing reading aids so they work as well at home as they do in the doctor's office.

The needs of nonsighted people are quite different than those of partially sighted persons. There is no single aid that allows them to read everything they encounter in daily life. We found that they need an assortment of aids to deal with different written materials. Because of this, we decided to focus our efforts on improving one particular aid.

We chose braille because it has many potentially desirable features. Braille materials are easy to skim through or reread. Braille is also convenient for taking simple notes, or labeling things like elevator buttons or groceries in the kitchen cupboard.

But, learning braille is a problem, especially for people who become blind as adults. It is like learning a foreign language except harder because you have to learn to read it with your fingers. It is also hard to learn without someone who knows how to read it. When we looked for a solution to these problems, we found one in a new consumer product by Texas Instruments called the "Magic Wand Speaking Reader". The reader was designed to help children learn to read by associating printed and spoken words. It uses special books that contain printed text and bar code like you see on many products. When the "Magic Wand" is passed over the bar code, the text is converted to synthetic speech.

We adapted the special books for braille teaching by simply placing braille over the text, and adding tactile symbols to make it easy to find the bar code. Our preliminary evaluations with novice and experienced adult braille readers have been encouraging. People learn to use the device quickly. They like its novelty and find the spoken reinforcement rewarding. Braille teachers like it because it gives them freedom to help more students and because students can learn at home. Sighted relatives like it because they can share the experience of learning braille. Administrators like it because it costs less than $50.

We are now designing books specifically for visually impaired adults. We are also working with manufacturers to obtain appropriate licenses, and to print books with braille and tactile symbols. Our first books will be printed using a new technique that produces raised symbols with a special ink, rather than embossing. This will reduce both their bulk and their cost. These will be distributed to public and private rehabilitation facilities for evaluation. If our evaluation is successful, we will work with rehabilitation organizations and retailers to market and distribute the product.

We are still a long way from achieving our ultimate goal. But, we are making progress. We have a better understanding of the needs and abilities of people who are visually impaired. We have found a way to satisfy at least one of these needs, and we are working on solutions for others. We could not have done this without the cooperation of disabled consumers, rehabilitation professionals, engineers and scientists. The VA's Rehabilitation R&D Centers are unique resources that facilitate this kind of cooperation.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions you or members of the committee may have.

STATEMENT OF WOODROW SEAMONE, PROJECT MANAGER, PROSTHETICS/ORTHOTICS RESEARCH PROJECT, FLEET SYSTEMS DEPARTMENT, THE JOHNS HOPKINS UNIVERSITY/APPLIED PHYSICS LABORATORY, LAUREL, MD

Mr. Chairman and members of the committee, my name is Woodrow Seamone. I am the Project Manager of the research program at the Johns Hopkins University Applied Physics Laboratory on the application of robotics to the handicapped. Management of this project is shared with Dr. Gerhard Schmeisser, Professor at the Johns Hopkins School of Medicine and Associate Director of Orthopedics at The Johns Hopkins Hospital.

A robot arm/work table system has been under development at Johns Hopkins beginning in 1974 as followup on the development of an electrically powered artificial arm. This work is sponsored by the Veterans Administration Rehabilitation Research and Development Service. The objective of this research activity is an electromechanical system which will enable persons with sound minds, but with no functional use of their limbs, such as high level quadriplegics, to perform a wide variety of useful manipulative tasks with a minimum of attendant assistance. An associated objective is the maintenance or enhancement of independent wheelchair mobility. A noteworthy constraint on the system is the requirement of $10,000 as the maximum cost to manufacture this robot arm.

The entire system includes the computer-controlled robot arm which is mounted on a work table. Positioned within reach of the arm on the table are an assortment of task-performance devices, including a telephone, typewriter or personal computer, reading stand, and dishware. The system also includes an electric wheelchair and a dual-purpose control subsystem designed to enable the user to selectively operate either the robot arm or the wheelchair. Task such as self feeding, answering the telephone, and use of a typewriter or personal computer are possible with this system. It is possible for the user to drive his wheelchair up to the work table to position himself as if he were at a desk, to operate the arm to perform the desired task, and then to drive away, all without attendant assistance.

The methodology employed on this project was to design and construct a basic robot/work table system and then progressively modify the system in accordance with recommendations of quadriplegics working with it. Early phases of the program concentrated on basic engineering development of the hardware and software provide a test system to evaluate the best approach for interaction with the user. Complementary adapters and fixtures were designed and fabricated in order to evaluate alternative means of carrying out the tasks mentioned.

The JHU/APL robot arm/work table system has been designed with the specific goal of enabling the quadriplegic to execute total tasks with little or no attendant assistance as well as minimum user effort. To accomplish those goals, a structured work table concept has been utilized, that is, the task performance devices—the local telephone, reading materials, typing paper, etc.—are located on the work table in specific places chosen to expedite manipulation of them by the robot. To carry out desired functions, the user can call up single axis motions of each of the robot joints. This mode of operation is tedious but most appropriate for execution of new or non-repetitive tasks. Alternatively, the user can call up any of a number of programmed sequences of motions predesigned to execute entire tasks without further input by the user. This mode of operation is most appropriate for repetitive and mechanically complex tasks such as feeding oneself, using the telephone, or loading paper into the typewriter. In either case, the user issues his commands to the robot through a chin motion sensor mounted on the wheelchair.

A noteworthy spin-off of this research program has been the development and subsequent successfull commercialization of a device operated by modified Morse Code input, which enables persons who are handicapped to the extent of being unable to use a keyboard, to operate computers. This device is being used by certain stroke victims as well as spinal cord injured persons.

A significant aspect of this research activity has been and continues to be the critical contribution by many veteran and non-veteran quadriplegic test pilots toward the original design and continuing evolution of the robot arm/work table system. Early clinical evaluation (1975–1982) was conducted on various models of the system using patient volunteers in the Baltimore area. Based on these highly successful trials, a decision was made at the VA to conduct more extensive clinical testing at two VA Medical Centers. Clinical evaluation has been underway since early 1983 on Spinal Cord Injury Centers at the VA Medical Centers in Richmond, Virginia and Cleveland, Ohio under the management of the Chiefs of these Services.

More than 12 quadriplegic volunteers have participated in these tests to date. As of the beginning of this year, the overall concensus was that the system could pro-

vide some much needed capability and independence for certain types of high level quadriplegics, but that certain engineering modifications are required to enhance its performance and reliability. One quadriplegic ate over 50 meals with this system. Another ate 16 meals with the system and consistently rated each eating experience as being excellent. This user volunteered to work with the Morse Code computer interface at the work table. He spent between 2 and 4 hours per day working at the computer and using the robot arm to handle the diskettes, telephone and reading materials. All users found operation of the system easy to learn and did not express concern about any part of the equipment as a threat to personal safety. Overall, these users recommended continuation of the development of this system.

The VA is in a final negotiation phase with a potential manufacturer for this system. This contract is expected to be let some time in 1984. Assuming continuation of funding, JHU/APL is planning to provide transition assistance during the manufacturing prototype stage. The relevance of this project to the VA mission is to provide an increased measure of independence to certain types of more severely afflicted quadriplegics. It can reduce required attendant service and has significant potential for enhancing the vocational capabilities of these people. Overall, it should improve the quality of their lives.

Mr. Chairman, this concludes my formal statement. I will be pleased to answer any questions you may have.

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STATEMENT OF THOMAS A. KROUSKOP, PH.D., ASSOCIATE PROFESSOR, BIOENGINEERING, BAYLOR COLLEGE OF MEDICINE, HOUSTON, TX

Mr. Chairman and members of the committee, my name is Thomas A. Krouskop, Ph.D. I am Head of the Rehabilitation Engineering Department at The Institute for Rehabilitation and Research in Houston, Texas, Associate Professor of Bioengineering at Baylor College of Medicine and Principal Investigator of the project entitled "Automated Fabrication of Lower Extremity Prosthetic Sockets", at the Veterans Administration Medical Center in Houston, Texas. The work I will be describing is an outgrowth of projects that were conducted while I served as Director of an NIHR sponsored Rehabilitation Engineering Center at The Institute for Rehabilitation and Research in Houston, Texas. In this context several research projects were developed that were directly concerned with the problems of fitting lower extremity prostheses. Specific techniques were developed to measure the adequacy of the fit of an artificial limb and to determine how to modify sockets to account for changes in shape and volume that commonly cause fitting problems during use. These changes in shape and volume are most commonly caused by changes in the users medical condition, age and activity levels. During this time a conceptual framework for using computer aided design and manufacturing techniques for fabricating sockets was developed. With the growing number of people who have amputations due to trauma, age or other medical problems that cause poor circulation in the legs, it is becoming increasingly difficult to continue to provide high quality services at reasonable costs, particularly to persons living in remote areas. About 10 years ago an attempt was made to streamline the prosthetic applicance delivery system through the use of regional fabrication centers, but problems of characterizing the shape of the stump and firmness of the tissue made the attempt marginally effective and in fact created delays in delivery of artificial limbs.

Our present VA sponsored project is an effort to capitalize on advances that have been made in a number of disciplines to provide high quality, cost effective services to our veterans who need artificial limbs by overcoming the problems of data transfer and reducing the amount of hand labor required to build an artificial limb. The project is based on the assumption that computer aided design and manufacturing techniques can be used to simulate the "art" developed by very skilled prosthetists in determining what shape the socket should have to effectively interface an artificial limb to the user's body. The amputee's residual limb is a structure with characteristics that change as the amputee performs various activities. Specifically shape changes can cause the tissue to move in the socket during use and cause the tissue to be irritated or even damaged. Predicting the shape of the loaded limb so that the residual member will experience force pattern relieving areas that are sensitive to pressure and abrasion during activities is the primary purpose of the skilled prosthetist in fitting a socket to a patient. In current practice, the socket shaping is a result of the prosthetist's experience and remains an art which requires considerable investments of time and experience. Such skilled persons are not uniformly available to all patients needing their services. This project has been established to describe the art of shaping a prosthetic socket and transforming that function into a

more quantitative science. It uses computer advanced analysis systems to noninvasively characterize the firmness of the soft tissue and technology to characterize shapes that have been developed in the ongoing program at the Veterans Administration Hospital in Houston and Baylor College of Medicine and in other specialized facilities in North America.

The goal is to enhance the use of the VA regional prosthetic distribution centers as central facilities where the economies of computer driven equipment can be realized in the production of artificial limbs and orthopedic footware. This is expected to reduce the decentralized hand labor now associated with most fitting. The use of technology for the processes of prescription and socket fabrication would become an advance in automation of real human consequence. To accomplish this task of creating the mold for a lower limb prosthetic socket using computer aided manufacturing techniques, the shape of the residual limb must be defined so that a computer can recognize and manipulate the data. The soft tissue comprising the limb must then be characterized in terms of compressibility. The prosthetist's art of palpating the tissue to determine its resilience must be replaced by an instrument. By extending the work done previously by others who have used ultrasound to characterize such things as the shape of an unborn fetus and the heart muscle as it contracts, a new device has been developed that determines how firm are the stump tissue. These data, along with the person's weight and observations about scars on the residual limb are used as input to a computer program. This program has been used quite successfully in the aerospace program and in mechanical design to study how materials deform when they are loaded. The output of this analysis then becomes input for a computer controlled cutter that can produce the mold that is needed to make a socket for an artificial limb. Once the efficacy of these techniques has been demonstrated by comparing the quality and costs of the product to the costs and quality associated with current prosthetist's work, it will be possible to use the same techniques to make shoes for persons who have need for specially designed orthopedic shoes.

The value of a research project such as this is not confined solely to its principal purpose. The results of the work often find wide-spread applications and affect care in other facets of the health care system. For example, the technique that is being developed to characterize the firmness of the muscle tissue has far reaching implications for monitoring noninvasively the condition of internal organs or parts, for instance the status of cardiac muscles after myocardial infarction, or the development of renal tumors masked within the kidney tissue.

By bring together technology from many disciplines it is possible to realize improvements in the service delivery system that will better meet the future needs of the VA amputee population and the Nation's elderly or traumatized population.

That concludes my statement, Mr. Chairman. I will be pleased to answer any questions you or members of the committee may have.

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STATEMENT OF MARGARET J. GIANNINI, M.D., DIRECTOR, REHABILITATION RESEARCH AND DEVELOPMENT SERVICE, VETERANS ADMINISTRATION CENTRAL OFFICE, WASHINGTON, DC

Mr. Chairman and members of the committee, my name is Margaret Joan Giannini, M.D. I am the Director of the Rehabilitation Research and Development Service of the Veterans Administration in VA Central Office, Washington, DC. I was appointed to this position on April 13, 1981. For 36 years as a clinician, researcher, professor and administrator, I have devoted my professional life to serving handicapped persons both nationally and internationally. I was privileged to have served as the first Director of the National Institute on Handicapped Research and currently am a member of the Institute of Medicine of the National Academy of Science.

I am delighted to have an opportunity this morning to present to you the VA/SEATTLE FOOT, an exciting new prosthetic foot developed in the VA Rehabilitation Research and Development program by Ernest M. Burgess, M.D. Dr. Burgess is the Principal Investigator of the Prosthetic Research Study at the VA Medical Center in Seattle, Washington. He is Clinical Professor of Orthopedic Surgery, University of Washington School of Medicine, and was recently designated a Distinguished Physician in the Veterans Administration by the VA Chief Medical Director.

The newly developed VA/SEATTLE Foot is a high performance foot designed to store the energy of weight bearing and to release this energy at the time of toe off roughly simulating the action of the gastrocnemius muscle in a normal person. It

does this by means of an internal "keel" or spring member that is designed to deflect under body load. The keel is made of high-strength plastic (delrin) and is scientifically designed to store energy as efficiently as possible. The foot itself is molded from high durability foam. The foot is attached to the leg prosthesis conventionally. The VA/Seattle Foot shows great promise for enhancing the quality of life for veterans with limb loss. Use of this foot will not only be cost effective but it will also provide many physical and psychological benefits including the opportunity to improve physical fitness among this large group of severely disabled veterans. Studies have indicated that there is a greater frequency of heart and arterial disease among lower limb amputees. This is no doubt attributable in part to the sedentary lifestyle of limb amputees. We anticipate that the VA/Seattle Foot, by facilitating increased physical activity, could positively impact on the expected longevity of lower limb amputees.

Research to develop an entire "family" of improved prostheses (artificial limbs) for lower limb amputees began at the VAMC Seattle, Washington in 1979. The research goals were to fabricate, evaluate and expedite for commercial manufacturing, artificial limbs which will permit a higher level of performance. Specifically, these prostheses would improve functional capability and comfort in order to allow the user greater vocational latitude and more varied, physically demanding recreation. These major objectives are planned for completion in Fiscal Year 1985.

A statistical review of several hundred lower limb amputees, primarily Vietnam veterans, questioned what activities they missed the most and how their quality of life could be enhanced by improved prosthetic devises. The majority were much less concerned about activity related to their various work demands than to the severe restraints on recreation. Most felt they could successfully compete in the workplace but sorely missed many sports and recreational endeavors which they had previously enjoyed. The most common functional loss was the ability to run. So many physical recreational activities involve the ability to run and to move quickly and decisively with one's legs that the expressed desire to be able to run led the list of needs.

Much of related research in the last few years has concentrated on high technology, particularly in the use of externally powered devises and complex hydraulic and other systems. Dr. Burgess and his staff set about to utilize high science but to relate it as practically as possible to the problem at hand. Accordingly, they recruited the services of materials and design engineers from industry, primarily the aircraft industry, and then proceeded to transfer industrial technology to lower limb prosthetics. The thesis was that materials-science, particularly composite materials, could provide inherent energy storage and release coupled with purposeful movement and stability.

In cooperation with Kinesiology Department at the University of Washington School of Physical Education Dr. Ernest M. Burgess and his team analyzed running gait in a number of amputees using the generally available prosthetic substitutes. Careful, scientific monitoring of the nature of amputee running provided the background for prosthetic advances. Information obtained in such a study of amputees running was used to develop a new prosthetic foot which combined energy characteristics so as to permit the amputee to move quickly, to run and to engage in many previously denied sports. These include racket sports, basketball, jogging and running, soccer, golf and others.

The foot has been clinically tested for the past year and a half on amputees across the United States. Its reception has been enthusiastic. Improvements in design and materials have been and are being made consistent with the use reports and suggestions. The Veterans Administration is now purchasing 500 such feet for distribution to VA Medical Centers throughout the country for selected use. Information collected from the use of these feet over a short period of time will permit release for commercial manufacture and general use both in the veterans and civilian populations.

The Prosthetics Research Study at Seattle is now proceeding to apply the same high quality (storage/release) concept to the remaining components of lower limb prostheses to include shanks, sockets, joints and suspension. Over the next year and a half to two years we will accelerate this technology transfer to produce what we believe will be an advanced, streamlined, relatively inexpensive and high performance, comfortable armamentarium. For example, when commercialy produced, the VA SEATTLE foot will not only be financially competitive with present less responsive appliances but should be even more cost effective.

Mr. Chairman, this concludes my formal statement. I would be pleased to answer any questions you may have and would now like to present Mr. James Mayer of Silver Spring, Maryland who is Staff Administrator for the Paralyzed Veterans of

America, Inc., Mr. Mayer is wearing two VA/SEATTLE Feet and who will demonstrate their use.

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STATEMENT OF DUDLEY S. CHILDRESS, PH.D., DIRECTOR, PROSTHETICS RESEARCH, VETERANS ADMINISTRATION LAKESIDE MEDICAL CENTER, CHICAGO, IL

Mr. Chairman and members of the committee, my name is Dudley S. Childress, Ph.D. I am Director of the Prosthetics Research Laboratory connected with the Veterans Administration Lakeside Medical Center (VALMC) in Chicago, Illinois. I am also Director of the Rehabilitation Engineering Program of the Northwestern University Medical School and am Professor of Electrical Engineering and Computer Science, Biomedical Engineering, and Orthopaedic Surgery at Northwestern University. At present I serve as President of the Rehabilitation Engineering Society of North America (RESNA). Prosthetics Research and Rehabilitation Engineering have been my areas of professional interest since 1966.

The human hand is one of the most marvelous instruments ever developed. Aristotle called it the "Instrument of Instruments". The human arm is subservient to the hand and operates almost subconsciously to place the hand in appropriate locations for prehension and other functions. That the human arm and hand can carry out extremely complex mechanical tasks without the human thinking about the process—in fact, he may be thinking about something else entirely (e.g. when doing math on a chalkboard)—is one of the astounding aspects of human motor control. In addition, our hands serve like eyes in gathering information from the environment around us.

The arm and hand are not only important because they do things but also because they may be seen. Yousuf Karsh, the well-known portrait photographer has said that hands reveal the personality and are a barometer of a person's being. Hands, like the eyes, tend to reveal the soul.

The loss of an arm is not only a physical loss of function, it is a psychological loss as well and this must be remembered in the management of arm amputees. Altered appearance and limitations of function influence the psyche, as do fears about being able to carry on a productive and creative life. In addition, large regions of the brain are given over to hand function (sensory and motor) and we do not know what effect there is when these areas lose their intended function because of arm amputation.

I could go into much more detail concerning the abilities and sensibilities of the human hand/arm system—a system we use almost constantly, but to which we seldom give thought. Rather, I want to talk about replacement of this system with artificial mechanisms (arm prostheses). I began with the human arm theme because I want you to realize some of the difficulties associated with replacing such an instrument and because I want you to be aware of some of the goals of artificial arm development; goals such as, (1) subconscious control of arm and hand movement, (2) multifunctional holding capabilities, (3) visually pleasing appearance to the eye (both structurally and through grace of motion), and (4) sensory abilities. Since the arm and hand mechanisms are almost always in our service and seldom break down even under rigorous working conditions, we also want artificial arms and hands to serve faithfully, with few repair problems, and to serve under many kinds of mechanically stressful conditions.

Even though we have a long way to go in perfecting artificial arms, much progress has been made in this area since the VA and other agencies began supporting efforts in this field in 1945. Naturally, there was a sudden surge of progress in the era 1945–1955. Subsequent research developments have been steady in coming, even if not so dramatically as in the early years. However, in recent years a new surge of activity has come about through the use of electric-powered arms controlled by miniature electronic systems. In some cases these arms are controlled rather naturally and somewhat subconsciously.

Some of these arms are controlled by myoelectric signals from remaining muscles in the limb. These bioelectric signals are created when a muscle contracts, much as the electrocardiogram is created when the heart contracts. These signals, used in conjunction with other body motions, can control electric-powered arms in skillful ways. I believe limbs of this kind are very important for veterans and the civilian population. The VA has been a leader in these developments.

This concludes my formal statement. I'll be pleased to answer questions you may have.